# MECH 202 PROJECT 2

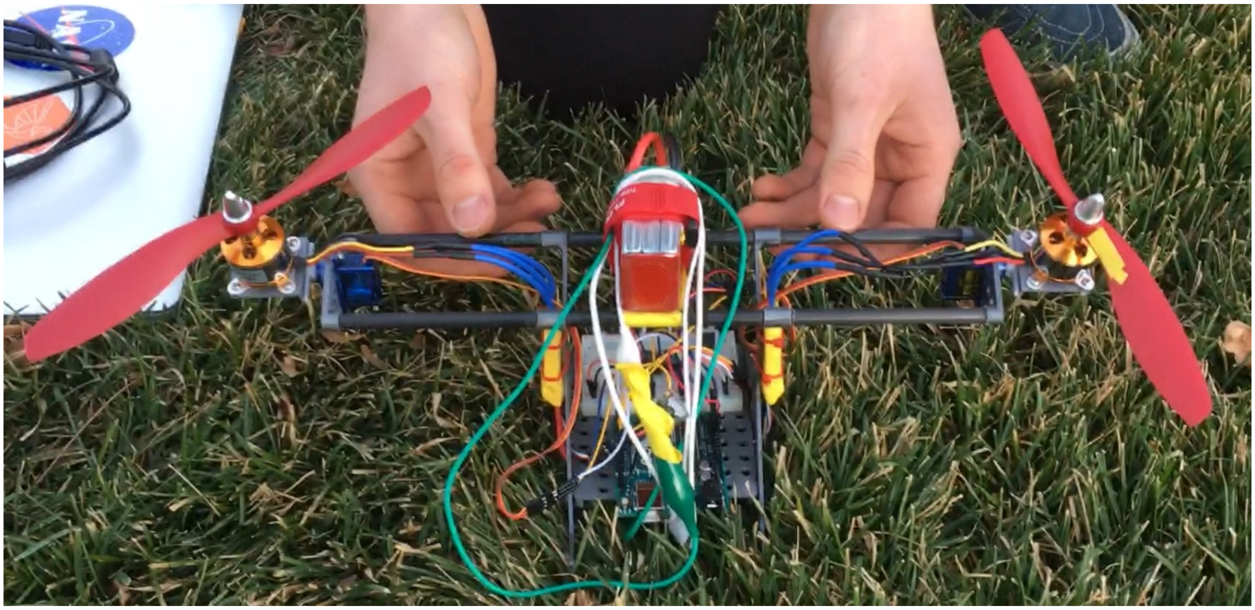
Group 2

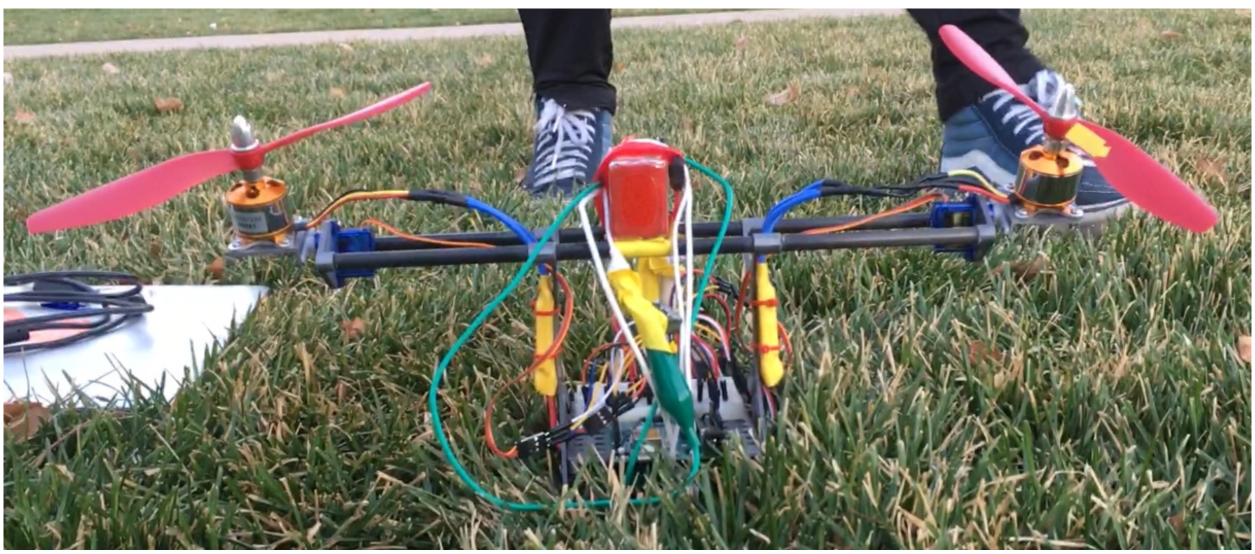
## GROUP MEMBERS

Erik Pranckh________epranckh@rams.colostate.edu
Drayton Browning___dbrowning@rams.colostate.edu
Tim Roberts________troberts@rams.colostate.edu
Jeremy Tabke_______jtabke@rams.colostate.edu

## Table of contents

***EPAND (Electrically Propelled Air Navigation Device)***





## 1.) ***Project Planning***

***Task Description List***

Table 1.1 – Critical Path

| Task | Title | Objective | Estimated Time (hr) | Lapsed Time (hr) |
|---|---|---|---|---|
| 1 | Concept Generation | Using at least three different methods generate multiple design concepts given constraints and specifications. | 4 | 4 |
| 2 | Prototype | Assemble chassis and all components of final design. | 12 | 16 |
| 3 | Engineering Analysis | Apply engineering concepts to device to prove functionality. | 2 | 6 |
| 4 | Device Description | Give in depth description of how the device operates, and guidelines to create a product like the device. | 4 | 6 |
| 5 | Model of Device | CAD model of Chassis | 7 | 7 |
| 6 | Bill of Materials | List of all materials required to fabricate device. Include cost, description, manufacturing process, and where the part was acquired. | 2 | 3 |
| 7 | Testing | Describe tests performed to verify that device meets specifications. | 10 | 8 |
| 8 | R&D Analysis | Analyze the key variables that will affect the performance of the device, and the ability for the device to accomplish each task. | 8 | 12 |
| 9 | Safety Analysis | Identify risk areas, hazards and a description of what was done to manage these. | 4 | 4 |
| 10 | Service & Support Plan | Plan to handle broken parts and emergency repairs on the device | 2 | 1 |
| 11 | Teamwork Analysis | Summary of lessons learned in preparing the device and the report for the competition. | 1 | 1 |
| 12 | Prepare Documents | Collect all relevant documents, and format report appropriately. | 5 | 6 |
| 13 | Failure Analysis | Describe why your device did not meet required tasks and how you would improve the device if the competition were held again. | 4 | 4 |

***Task Templates***

Table 1.2 – Task 1

| Project Planning | |
|---|---|
| **Design Organization: MECH 202** | **Date: 9/12/17** |
| Proposed Product Name: EPAND | |
| **Task 1** | **Name of Task**: Concept generation<br>**Objective** : Analyze trade-offs, pros, cons, goals, and constraints of the EPGND, generate a feasible design of a functional automated flying device to fly itself across the gym and land.<br>**Deliverables:** List of trade off points<br>**-**List of Pros and cons<br>**-**Layout of goals<br>-List of Constraints<br>**Decisions needed**:<br>Decision 1: Personnel to create lists<br>Decision 2: When to create Lists<br>**Personnel needed**<br>Title: All Hours: 1<br>Title: Hours:<br>**Time estimate** Total hours: 4 Lapsed time(include units): 0 hrs<br>**Sequence:** Predecessors: N/A Successors: 2-13<br>Start Date: 9/12/17 Finish Date: 9/19/17<br>**Costs:** Capital Equipment **$0** Disposables: $0 |
| Team member: Tim Roberts | Prepared by: Erik Pranckh |
| Team member: Jeremy Tabke | Checked by: |
| Team member: Drayton Browning | Approved by: |
| Team member: Erik Pranckh | |
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Table 1.3– Task 2

# Project Planning

| | |
|---|---|
| **Design Organization: MECH 202** | **Date: 9/12/17** |
| Proposed Product Name: EPAND | |
| **Task 2** | **Name of Task**: Prototype |
| | **Objective** : Design and build a working prototype. Lift off, translate, land. |
| | **Deliverables:** functional prototype, drawing, and design process outline |
| | **Decisions needed**:<br>Decision 1: Personnel to generate design<br>Decision 2: Personnel to construct design<br>Decision 3: Personnel to program arduino |
| | **Personnel needed**<br>Title: Jeremy Hours: 4<br>Title: Erik Hours: 4<br>Title: Drayton Hours: 4 |
| | **Time estimate** Total hours: 12 Lapsed time(include units): 0 hrs |
| | **Sequence:** Predecessors: 1 Successors: 3-14<br>Start Date: 9/14/17 Finish Date: 10/14/17 |
| | **Costs:** Capital Equipment **$70** Disposables: $20 |
| Team member: Tim Roberts | Prepared by: Erik Pranckh |
| Team member: Jeremy Tabke | Checked by: |
| Team member: Drayton Browning | Approved by: |
| Team member: Erik Pranckh | |

Table 1.4 – Task 3

| Project Planning | |
|---|---|
| **Design Organization: MECH 202** | **Date: 9/12/17** |
| Proposed Product Name: EPAND | |
| **Task** 3 | **Name of Task**: Engineering Analysis |
| | **Objective**: Demonstrate how you have used engineering concepts from past experience (i.e. class) in the design and construction of the assembly. |
| | **Deliverables:** Typed and professional engineering analysis of the engineering process. Must be in depth, large part of grade. |
| | **Decisions needed**:<br>Decision 1: Personnel to write analysis<br>Decision 2: Time to write analysis |
| | **Personnel needed**<br>Title: Tim Hours: 2<br>Title: Hours: |
| | **Time estimate** Total hours: 2 Lapsed time(include units): 0 hrs |
| | **Sequence:** Predecessors: 2 Successors: 4, 12<br>Start Date: 10/14/17 Finish Date: 10/17/17 |
| | **Costs:** Capital Equipment **$0** Disposables: $0 |
| Team member: Tim Roberts | Prepared by: Erik Pranckh |
| Team member: Drayton Browning | Checked by: |
| Team member: Jeremy Tabke | Approved by: |
| Team member: Erik Pranckh | |
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Table 1.5 – Task 4

<table>
<tr><td colspan="2">Project Planning</td></tr>
<tr><td>Design Organization: MECH 202</td><td>Date:</td></tr>
<tr><td colspan="2">Proposed Product Name: EPAND</td></tr>
<tr><td rowspan="9">Task<br>4</td><td>Name of Task: Device Description</td></tr>
<tr><td>Objective : Explain how to make a device similar to yours, the process of design and tasks, identify any critical elements or features that add to reliability, and features that make the device unique.</td></tr>
<tr><td>Deliverables: Annotated drawings and photos<br>-Easy to follow processes and descriptions</td></tr>
<tr><td>Decisions needed:<br>Decision 1: Personnel to write description and compile information<br><br>Decision 2:</td></tr>
<tr><td>Personnel needed<br>Title: Tim Hours: 2<br>Title: Erik Hours: 2</td></tr>
<tr><td>Time estimate Total hours: 4 Lapsed time(include units): 0hrs</td></tr>
<tr><td>Sequence: Predecessors: 1,2 Successors: 12<br><br>Start Date: 10/17/17 Finish Date: 10/23/17</td></tr>
<tr><td>Costs: Capital Equipment $0 Disposables: $0</td></tr>
<tr><td></td></tr>
<tr><td>Team member: Tim Roberts</td><td>Prepared by: Erik Pranckh</td></tr>
<tr><td>Team member: Drayton Browning</td><td>Checked by:</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td>Approved by:</td></tr>
<tr><td>Team member: Erik Pranckh</td><td></td></tr>
<tr><td colspan="2">The Mechanical Design Process Designed by Professor David G. Ullman<br>Copyright 2008, McGraw Hill Form # 10.0</td></tr>
</table>

Table 1.6 – Task 5

| Project Planning | |
|---|---|
| **Design Organization: MECH 202** | **Date:9/12/17** |
| Proposed Product Name: EPAND | |
| **Task 5** | **Name of Task**: Model of Device |
| | **Objective** : Create an Assembly model of the EPAND using CAD |
| | **Deliverables:** Assembly diagram of most important parts. |
| | **Decisions needed**:<br>Decision 1: personnel to create models<br>Decision 2: time to create models |
| | **Personnel needed**<br>Title: Drayton Hours: 4<br>Title: Jeremy Hours: 3 |
| | **Time estimate** Total hours: 7 Lapsed time(include units): 0 hrs |
| | **Sequence:** Predecessors: 1,2 Successors:4,12<br>Start Date: 10/17/17 Finish Date: 10/26/17 |
| | **Costs:** Capital Equipment **$0** Disposables: $0 |
| Team member: Tim Roberts | Prepared by: Erik Pranckh |
| Team member: Drayton Browning | Checked by: |
| Team member: Jeremy Tabke | Approved by: |
| Team member:Erik Pranckh | |
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Table 1.7 – Task 6

# Project Planning

<table>
<tr><td>Design Organization: MECH 202</td><td>Date: 9/12/17</td></tr>
<tr><td colspan="2">Proposed Product Name: EPAND</td></tr>
<tr><td rowspan="9">Task 6</td><td>Name of Task: Bill of Material</td></tr>
<tr><td>Objective : Create a document showing the cost of each item required to create device, where each item can be obtained, total cost of assembly, How much was spent in total.</td></tr>
<tr><td>Deliverables: completed typed bill of materials</td></tr>
<tr><td>Decisions needed:<br>Decision 1: personnel to write bill of materials<br><br>Decision 2: Time needed to create bill of materials</td></tr>
<tr><td>Personnel needed<br>Title: Erik Hours: 2<br>Title: Hours:</td></tr>
<tr><td>Time estimate Total hours: 2 Lapsed time(include units): 0hrs</td></tr>
<tr><td>Sequence: Predecessors: 1,2 Successors: 12<br><br>Start Date: 10/26/17 Finish Date: 10/31/17</td></tr>
<tr><td>Costs: Capital Equipment $0 Disposables: $0</td></tr>
<tr><td></td></tr>
<tr><td>Team member: Tim Roberts</td><td>Prepared by:Erik Pranckh</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td>Checked by:</td></tr>
<tr><td>Team member: Drayton Browning</td><td>Approved by:</td></tr>
<tr><td>Team member: Erik Pranckh</td><td></td></tr>
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</table>

Table 1.8 – Task 8

| Project Planning | |
|---|---|
| **Design Organization: MECH 202** | **Date:9/12/17** |
| Proposed Product Name: EPAND | |
| **Task 7** | **Name of Task**: Testing |
| | **Objective** : Describe the tests performed to verify that the device can meet all requirements. Show test results. |
| | **Deliverables:** Typed description of testing and organized layout of test results. |
| | **Decisions needed**:<br>Decision 1: personnel to conduct testing<br><br>Decision 2: personnel to document testing |
| | **Personnel needed**<br>Title: Jeremy Hours: 5<br>Title: Erik Hours: 5 |
| | **Time estimate** Total hours: 10 Lapsed time(include units): 0hrs |
| | **Sequence:** Predecessors: 1,2 Successors: 12<br><br>Start Date: 10/31/17 Finish Date: 11/9/17 |
| | **Costs:** Capital Equipment **$0** Disposables: $0 |
| Team member: Tim Roberts | Prepared by:Erik Pranckh |
| Team member: Jeremy Tabke | Checked by: |
| Team member: Drayton Browning | Approved by: |

Table 1.9 – Task 8

<table>
<tr><td colspan="2">Project Planning</td></tr>
<tr><td>Design Organization: MECH 202</td><td>Date: 9/12/17</td></tr>
<tr><td colspan="2">Proposed Product Name: E.P.A.N.D</td></tr>
<tr><td rowspan="8">Task<br>8</td><td>Name of Task: Reliability and Design Margin Analysis</td></tr>
<tr><td>Objective : Identify and statistically analyze the key areas of variability that will affect the performance and ability of the device to accomplish all tasks.<br>Analyze test results and the anticipated variability to identify how to make the design better.<br>List improvements based on the analysis.</td></tr>
<tr><td>Deliverables: Analysis of variability of the design<br>Test results analysis<br>List of improvements</td></tr>
<tr><td>Decisions needed:<br>Decision 1: Personnel to complete analysis<br><br>Decision 2: Identify key areas of variability</td></tr>
<tr><td>Personnel needed<br>Title: Tim Hours: 4<br>Title: Drayton Hours: 4</td></tr>
<tr><td>Time estimate Total hours: 8 Lapsed time(include units): 0</td></tr>
<tr><td>Sequence: Predecessors: 2, 7 Successors: 7, 9, 12<br><br>Start Date: 11/9/17 Finish Date: 11/14/17</td></tr>
<tr><td>Costs: Capital Equipment $0 Disposables: $0</td></tr>
<tr><td>Team member: Tim Roberts</td><td>Prepared by: Tim Roberts</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td>Checked by:</td></tr>
<tr><td>Team member: Drayton Browning</td><td>Approved by:</td></tr>
<tr><td>Team member: Erik Pranckh</td><td></td></tr>
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</table>

Table 1.10 – Task 9

<table>
<tr><td colspan="2">Project Planning</td></tr>
<tr><td>Design Organization:<br>MECH 202</td><td>Date: 9/12/17</td></tr>
<tr><td colspan="2">Proposed Product Name: E.P.A.N.D</td></tr>
<tr><td rowspan="8">Task<br>9</td><td>Name of Task: Safety Analysis</td></tr>
<tr><td>Objective : Analyze risk areas, hazard risks, and what was done to minimize critical hazards</td></tr>
<tr><td>Deliverables: Analysis of safety risk</td></tr>
<tr><td>Decisions needed:<br>Decision 1: Areas of risk<br><br>Decision 2:</td></tr>
<tr><td>Personnel needed<br>Title: Jeremey Hours: 2<br>Title: Erik Hours: 2</td></tr>
<tr><td>Time estimate Total hours: 4 Lapsed time(include units): 0</td></tr>
<tr><td>Sequence: Predecessors: 2, 5, 7 Successors: 10, 12<br><br>Start Date: 11/9/17 Finish Date: 11/14/17</td></tr>
<tr><td>Costs: Capital Equipment $0 Disposables: $0</td></tr>
<tr><td>Team member: Drayton Browning</td><td>Prepared by: Tim Roberts</td></tr>
<tr><td>Team member: Erik Pranckh</td><td>Checked by:</td></tr>
<tr><td>Team member: Tim Roberts</td><td>Approved by:</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td></td></tr>
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</table>

Table 1.11 – Task 10

<table>
<tr><td colspan="2">Project Planning</td></tr>
<tr><td>Design Organization: MECH 202</td><td>Date: 9/12/17</td></tr>
<tr><td colspan="2">Proposed Product Name: EPAND</td></tr>
<tr><td rowspan="8">Task 10</td><td>Name of Task: Service and Support Plan</td></tr>
<tr><td>Objective : Create a plan to in case of part failure and if emergency repairs are required</td></tr>
<tr><td>Deliverables: Spare parts (if necessary)<br>Plan of action in case of problems</td></tr>
<tr><td>Decisions needed:<br>Decision 1: Parts that are susceptible to failure</td></tr>
<tr><td>Personnel needed<br>Title: Jeremy Hours: 1<br>Title: Drayton Hours: 1</td></tr>
<tr><td>Time estimate Total hours: 2 Lapsed time(include units): 0</td></tr>
<tr><td>Sequence: Predecessors: 2, 3, 7, 8, Successors: 12<br><br>Start Date: 11/14/17 Finish Date:11/16/17</td></tr>
<tr><td>Costs: Capital Equipment $? Disposables: $0</td></tr>
<tr><td>Team member: Tim Roberts</td><td>Prepared by: Tim Roberts</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td>Checked by:</td></tr>
<tr><td>Team member: Erik Pranckh</td><td>Approved by:</td></tr>
<tr><td>Team member: Drayton Browning</td><td></td></tr>
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</table>

Table 1.12 – Task 11

| **Project Planning** | |
|---|---|
| **Design Organization: MECH 202** | **Date: 9/12/17** |
| Proposed Product Name: EPAND | |
| **Task 11** | **Name of Task**: Teamwork Analysis |
| | **Objective** : Analyze what was learned in preparing the device as related to teamwork |
| | **Deliverables:** Team contract<br>Summary of learned lessons |
| | **Decisions needed**:<br>Decision 1: Important aspects of teamwork as related to project |
| | **Personnel needed**<br>Title: All people Hours: 1 |
| | **Time estimate** Total hours: 1 Lapsed time(include units): 0 |
| | **Sequence:** Predecessors: N/A Successors: 12<br>Start Date: 11/21/17 Finish Date: 11/28/17 |
| | **Costs:** Capital Equipment $0 Disposables: $0 |
| Team member: Tim Roberts | Prepared by: Tim Roberts |
| Team member: Drayton Browning | Checked by: |
| Team member: Erik Pranckh | Approved by: |
| Team member: Jeremy Tabke | |
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Table 1.13 – Task 12

<table>
<tr><td colspan="2">Project Planning</td></tr>
<tr><td>Design Organization:<br>MECH 202</td><td>Date: 9/12/17</td></tr>
<tr><td colspan="2">Proposed Product Name: EPAND</td></tr>
<tr><td rowspan="8">Task 12</td><td>Name of Task: Prepare all documents</td></tr>
<tr><td>Objective : Prepare documents for the final report</td></tr>
<tr><td>Deliverables: Final, revised documents for report</td></tr>
<tr><td>Decisions needed:<br>Decision 1: Necessary revisions for report</td></tr>
<tr><td>Personnel needed<br>Title: All personnel Hours: 5</td></tr>
<tr><td>Time estimate Total hours: 5 Lapsed time(include units): 0</td></tr>
<tr><td>Sequence: Predecessors: 1 - 11<br>Successors: 13<br><br>Start Date:12/2/17 Finish Date: 12/3/17</td></tr>
<tr><td>Costs: Capital Equipment $0 Disposables: $0</td></tr>
<tr><td>Team member: Drayton Browning</td><td>Prepared by: Tim Roberts</td></tr>
<tr><td>Team member: Erik Pranckh</td><td>Checked by:</td></tr>
<tr><td>Team member: Jeremy Tabke</td><td>Approved by:</td></tr>
<tr><td>Team member: Tim Roberts</td><td></td></tr>
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Table 1.14 – Task 13

# Project Planning

| | |
|---|---|
| **Design Organization: MECH 202** | **Date: 9/12/17** |
| Proposed Product Name: | EPAND |
| **Task** 13 | **Name of Task**: Failure Analysis |
| | **Objective** : Analyze how device would be improved if competition is held again, if group did not finish in top three. |
| | **Deliverables:** Description of why device did not meet the required tasks and improvements that would be made |
| | **Decisions needed**:<br>Decision 1: Modes of failure |
| | **Personnel needed**<br>Title: All personnel Hours: 4 |
| | **Time estimate** Total hours: 4 Lapsed time(include units): 0 |
| | **Sequence:** Predecessors: 1-12 Successors: N/A<br>Start Date: 12/2/17 Finish Date: 12/5/17 |
| | **Costs:** Capital Equipment $0 Disposables: $0 |
| Team member: Tim Roberts | Prepared by: Tim Roberts |
| Team member: Erik Pranckh | Checked by: |
| Team member: Jeremy Tabke | Approved by: |
| Team member: Drayton Browning | |
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| | Task | Personnel |
|---|---|---|
| 1 | Concept Generation | People 4 / 1hr |
| 2 | Prototype | People 3 / 12hr |

| | | |
|---|---|---|
| 3 | Engineering Analysis | People 1 / 2hr |
| 4 | Device Description | People 2 / 4hr |
| 5 | Model of Device | People 2 / 7hr |
| 6 | Bill of Material | People 1 / 2hr |
| 7 | Testing | People 2 / 10hr |
| 8 | Reliability and Design Margin Analysis | People 2 / 8hr |
| 9 | Safety Analysis | People 2 / 4hr |
| 10 | Service and Support Plan | People 2 / 2hr |
| 11 | Teamwork Analysis | People 4 / 1hr |
| 12 | Prepare all Documents | People 4 / 5hr |
| 13 | Failure Analysis | People 4 / 4hr |

Table 1.15 – Critical Path

***DSM Chart & Critical Path***

| X | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | | | | | | | | | |
| 2 | X | 2 | | | | | | | | | | | |
| 3 | | X | 3 | | | | | | | | | | |
| 4 | X | X | | 4 | X | | | | | | | | |
| 5 | X | X | | | 5 | | | | | | | | |
| 6 | X | X | | | | 6 | | | | | | | |
| 7 | X | X | | | | | 7 | | | | | | |
| 8 | | X | | | | | | | | | | | |
| 9 | | X | | | X | | X | | 9 | | | | |
| 10 | | X | X | | | | X | X | | 10 | | | |
| 11 | X | | | | | | | | | | 11 | | |
| 12 | X | X | X | X | X | X | X | X | X | X | X | 12 | |
| 13 | X | X | X | X | X | X | X | X | X | X | X | X | 13 |

Table 1.16 – DSM Chart

***Gantt Charts***

***Week 1***

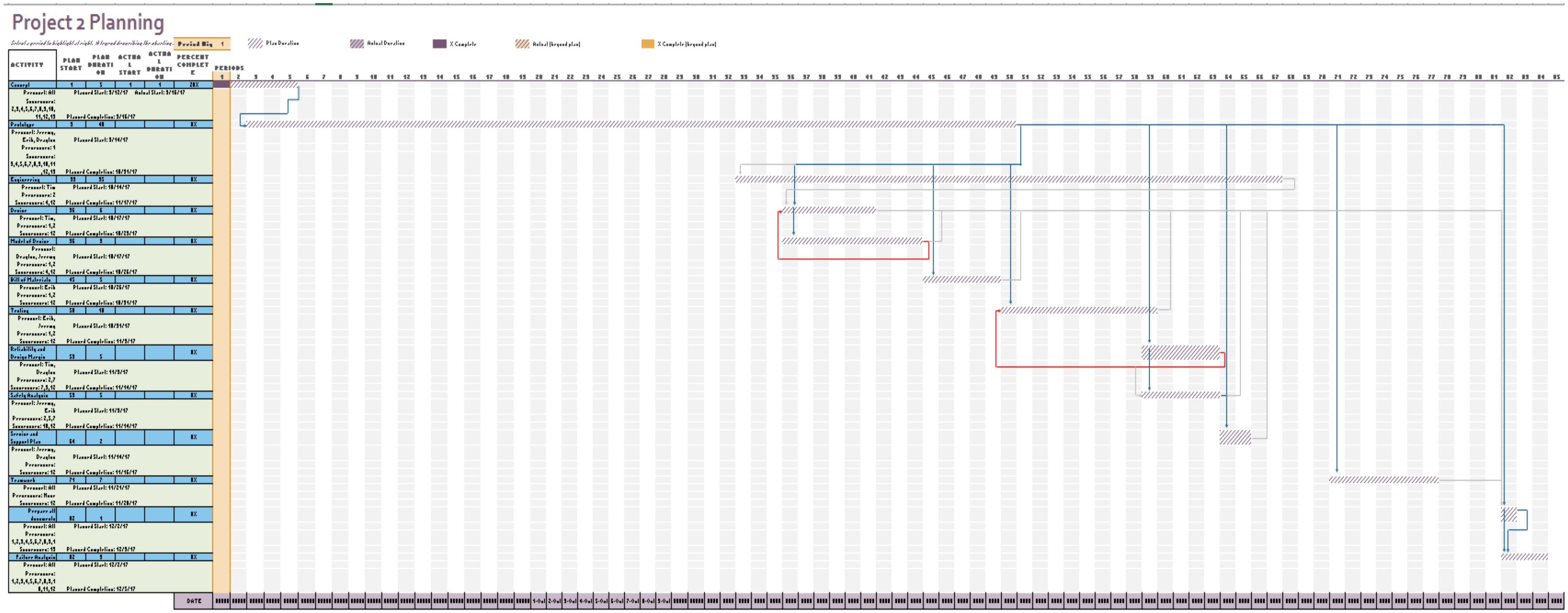


Fig. 1.1 – Week 1

### *Week 2*

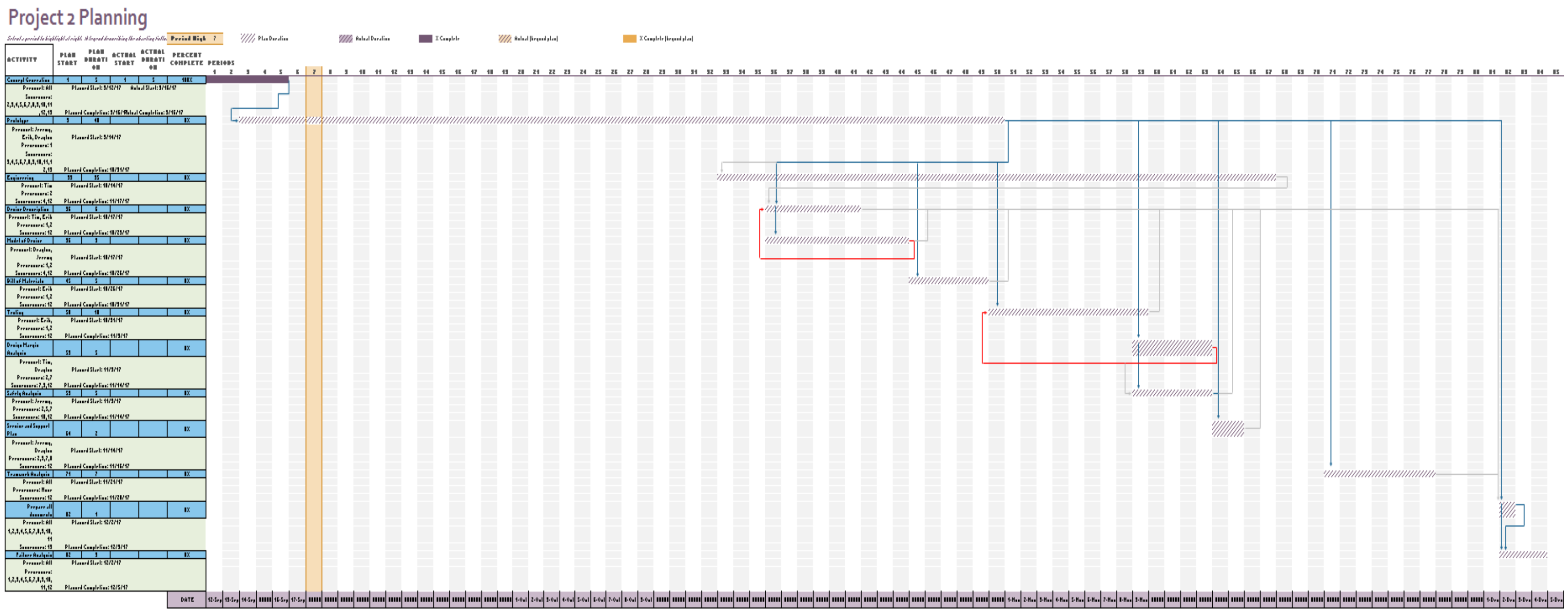


Fig. 1.2 – Week 2

## *Week 3*

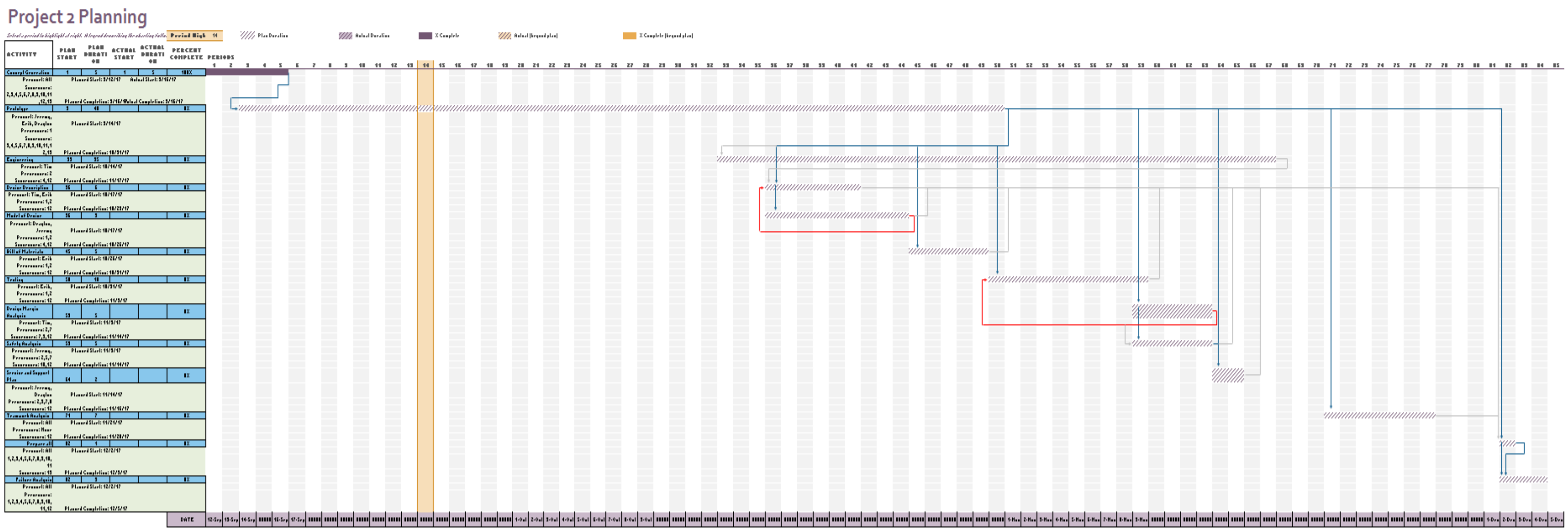


Fig. 1.3 – Week 3

## *Week 4*

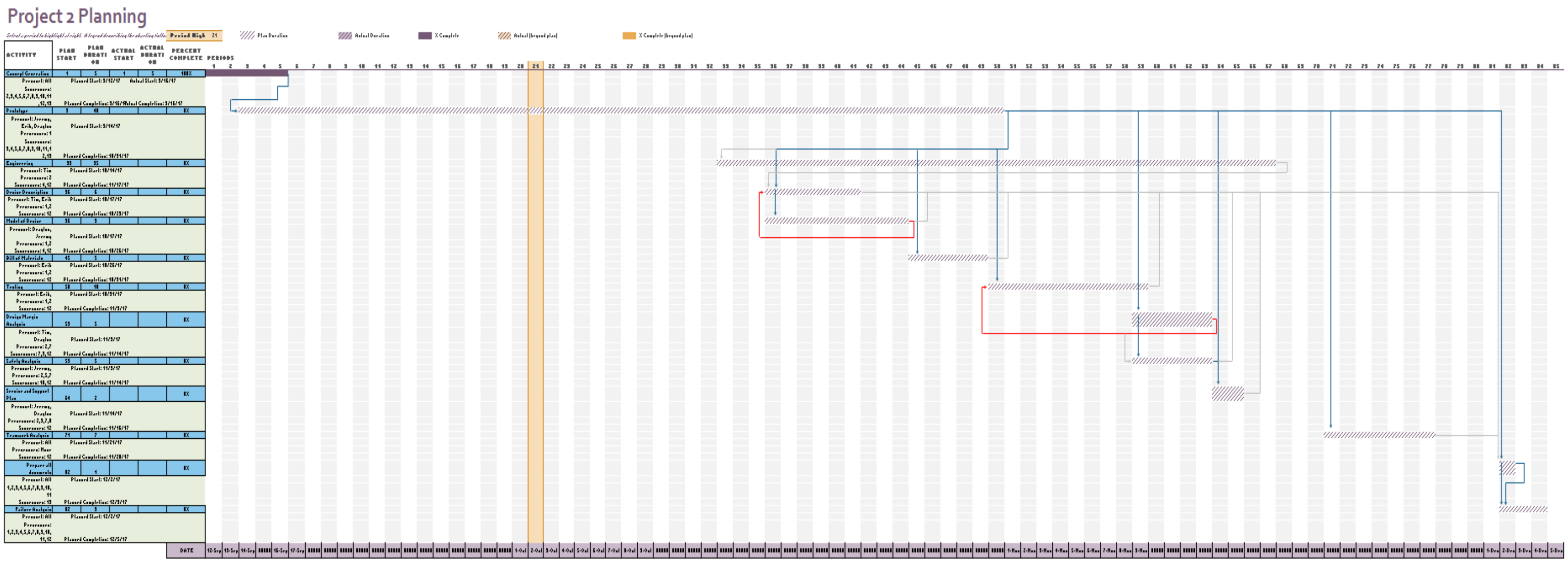


Fig. 1.4 – Week 4

## *Week 5*

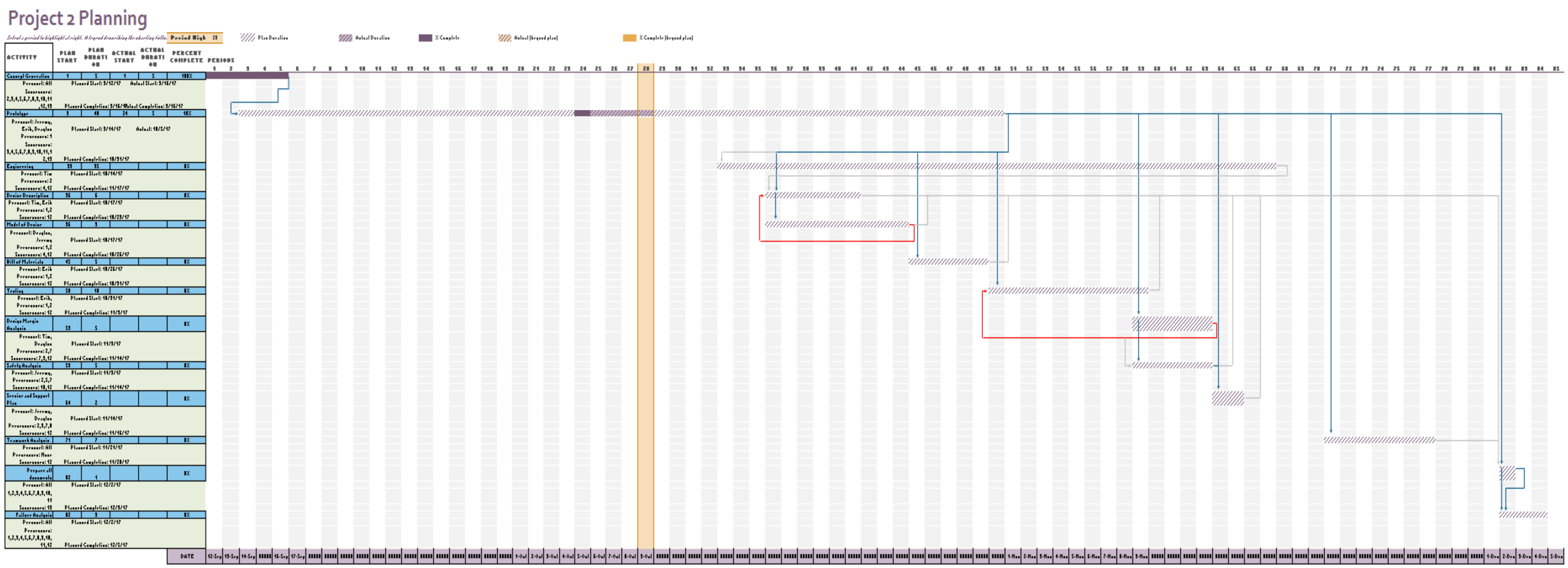


Fig. 1.5 – Week 5

***Week 6***

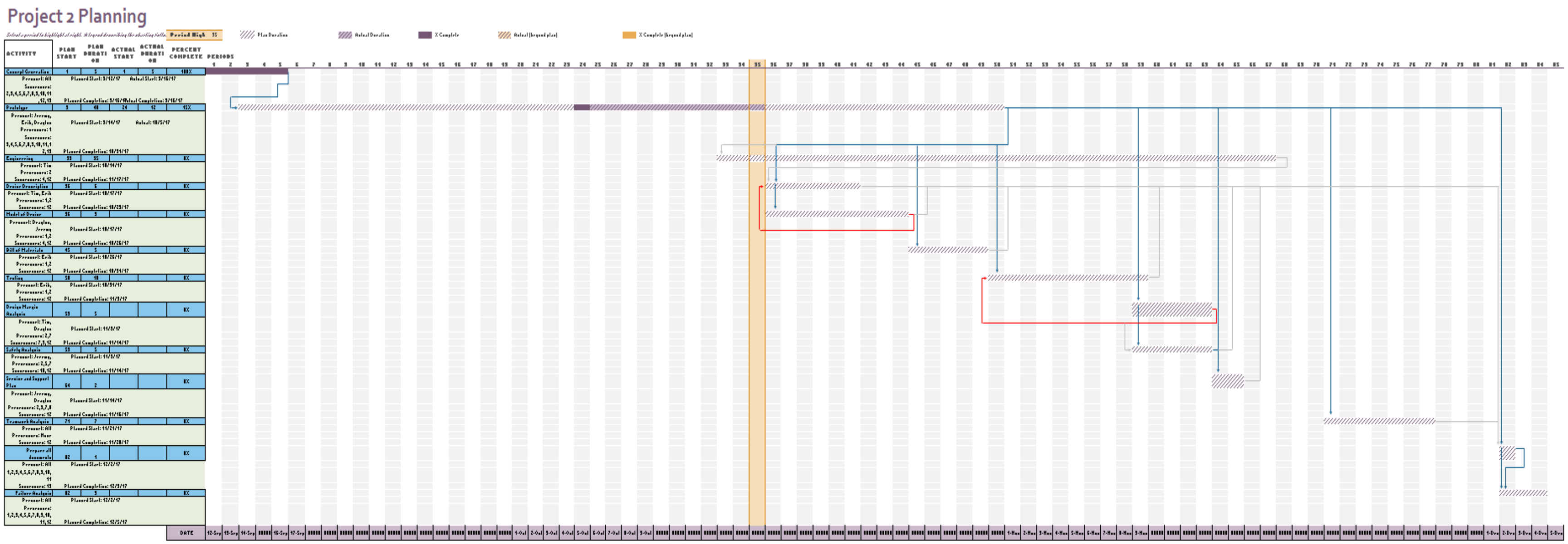


Fig. 1.6 – Week 6

## *Week 7*

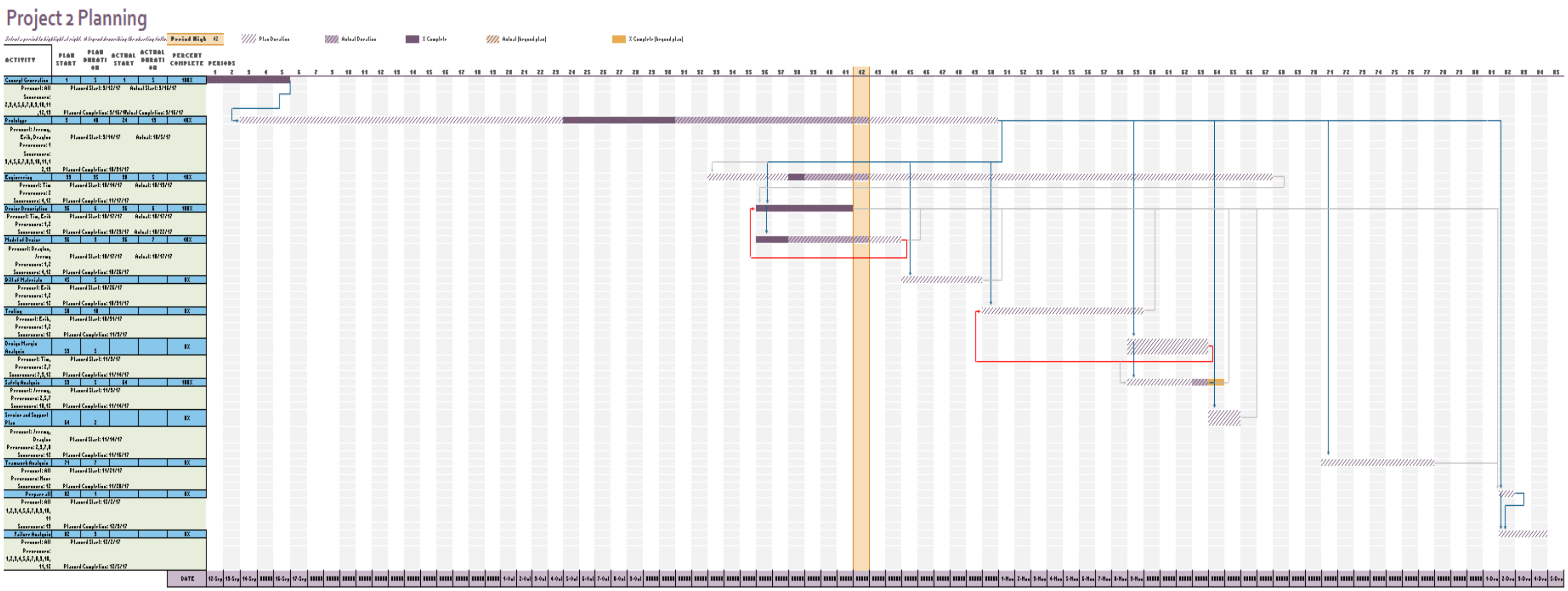


Fig. 1.7 – Week 7

## *Week 8*

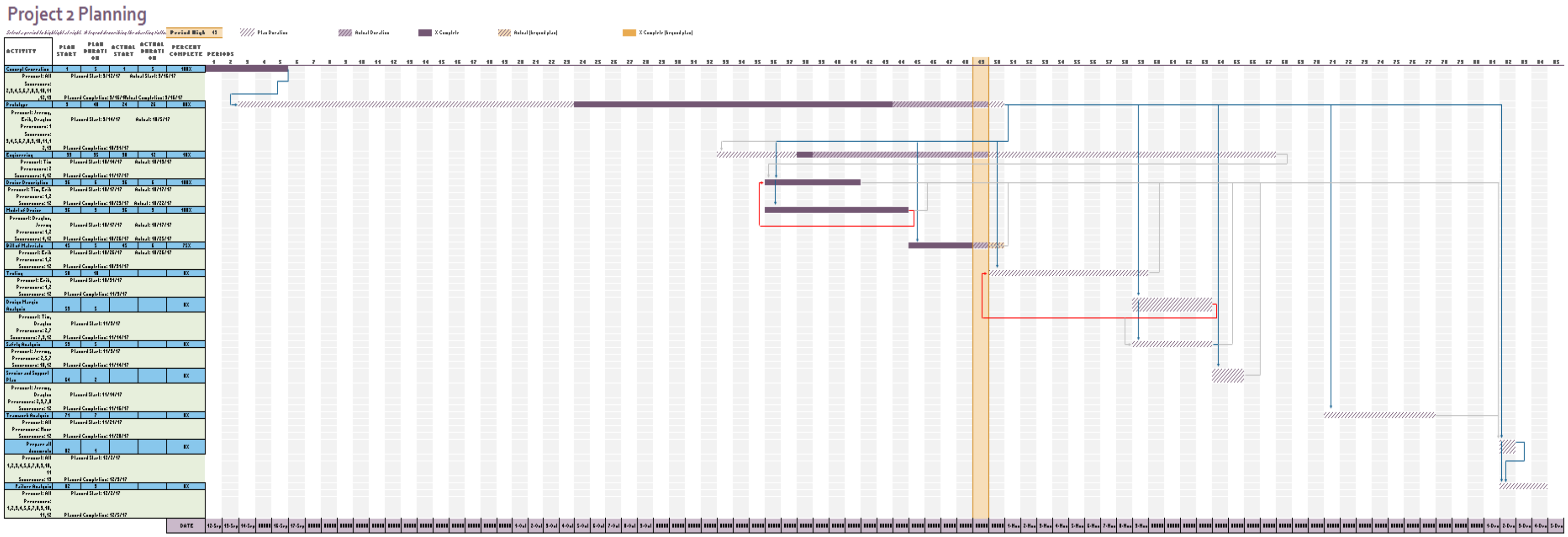


Fig. 1.8 – Week 8

***Week 9***

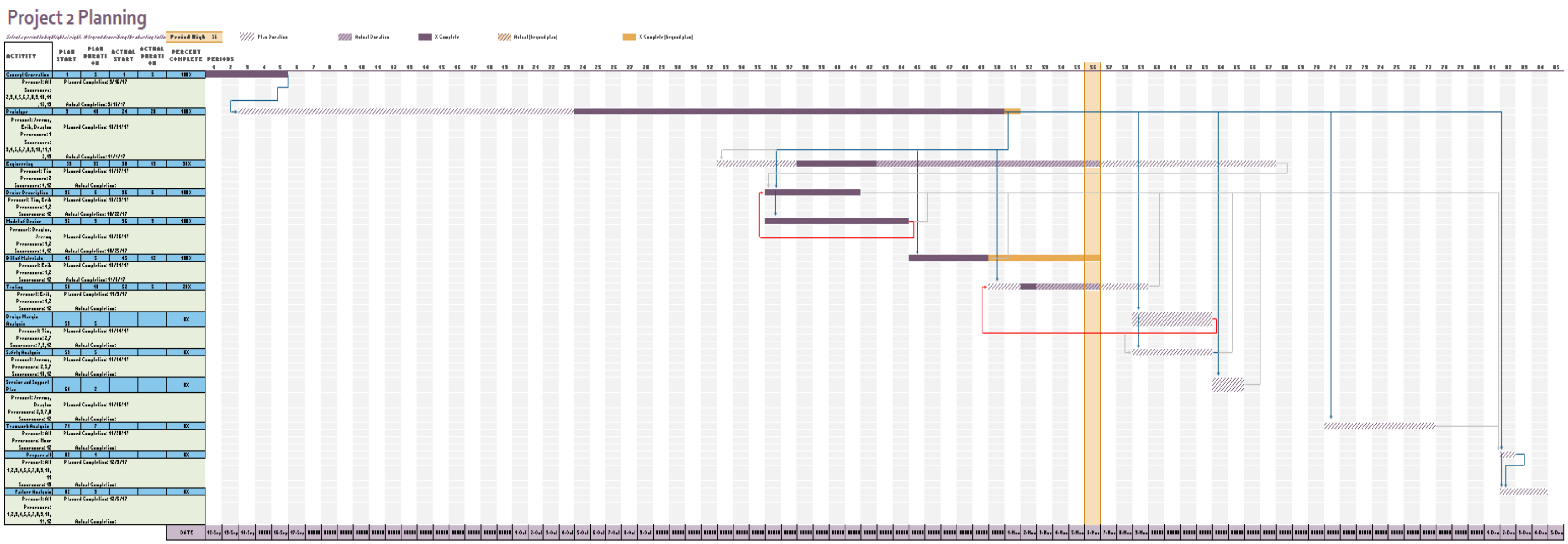


Fig. 1.9 – Week 9

***Week 10***

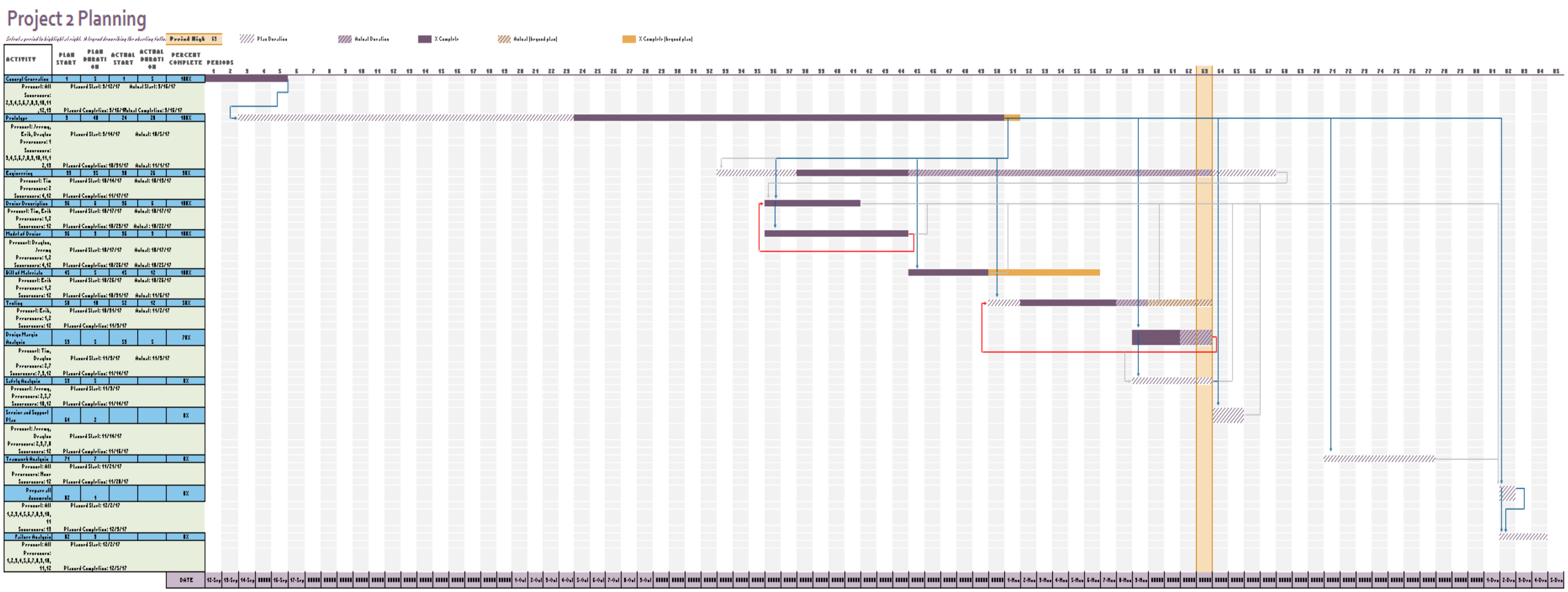


Fig. 1.10 – Week 10

***Week 11***

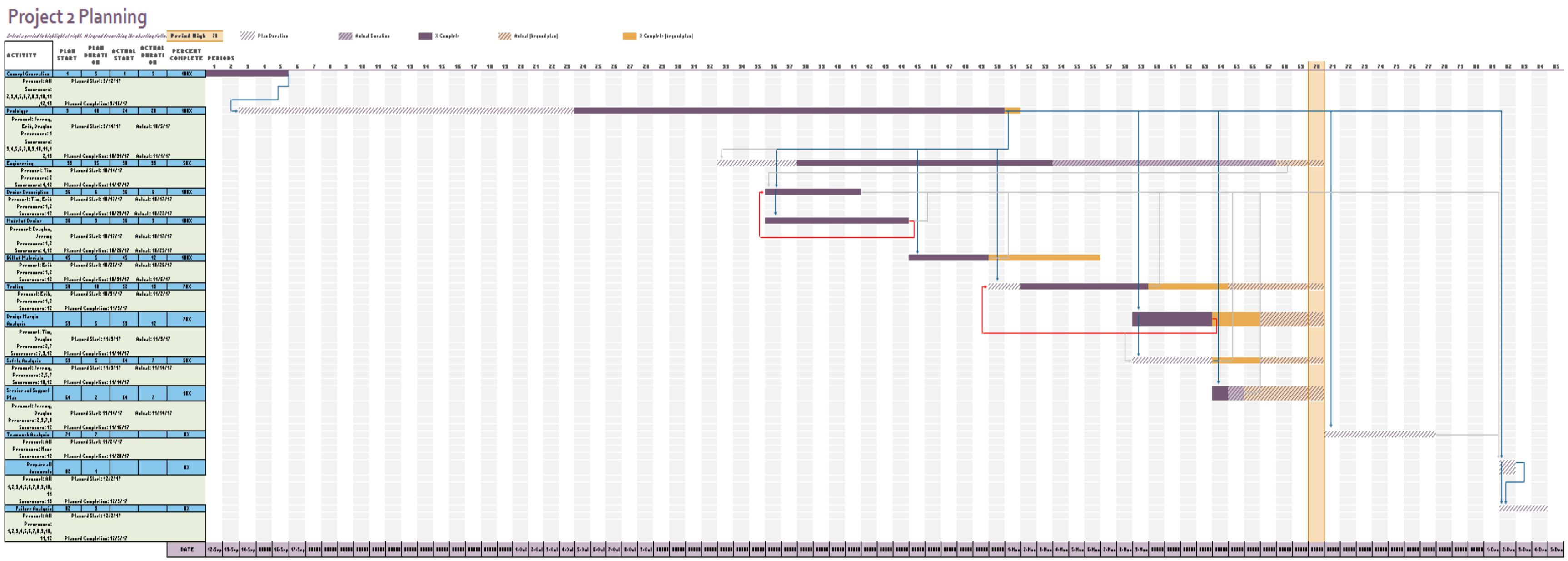


Fig. 1.11 – Week 11

***Week 12***

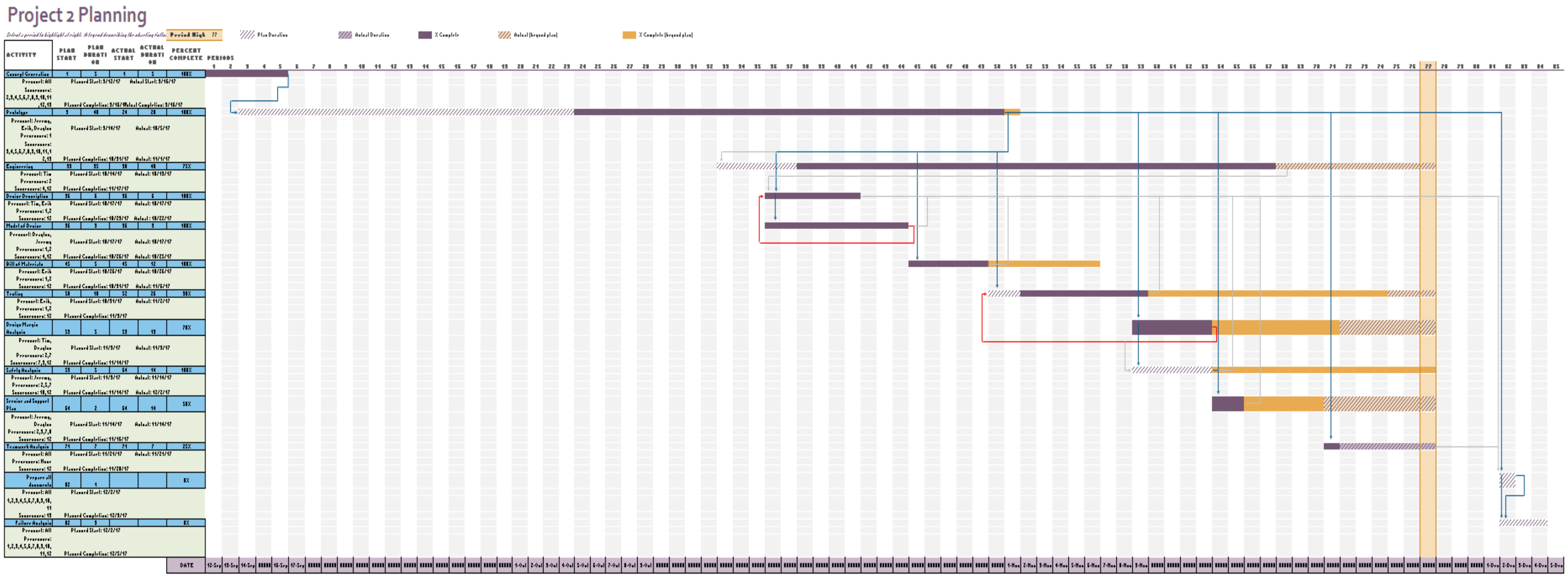


Fig. 1.12 – Week 12

### *Week 13*

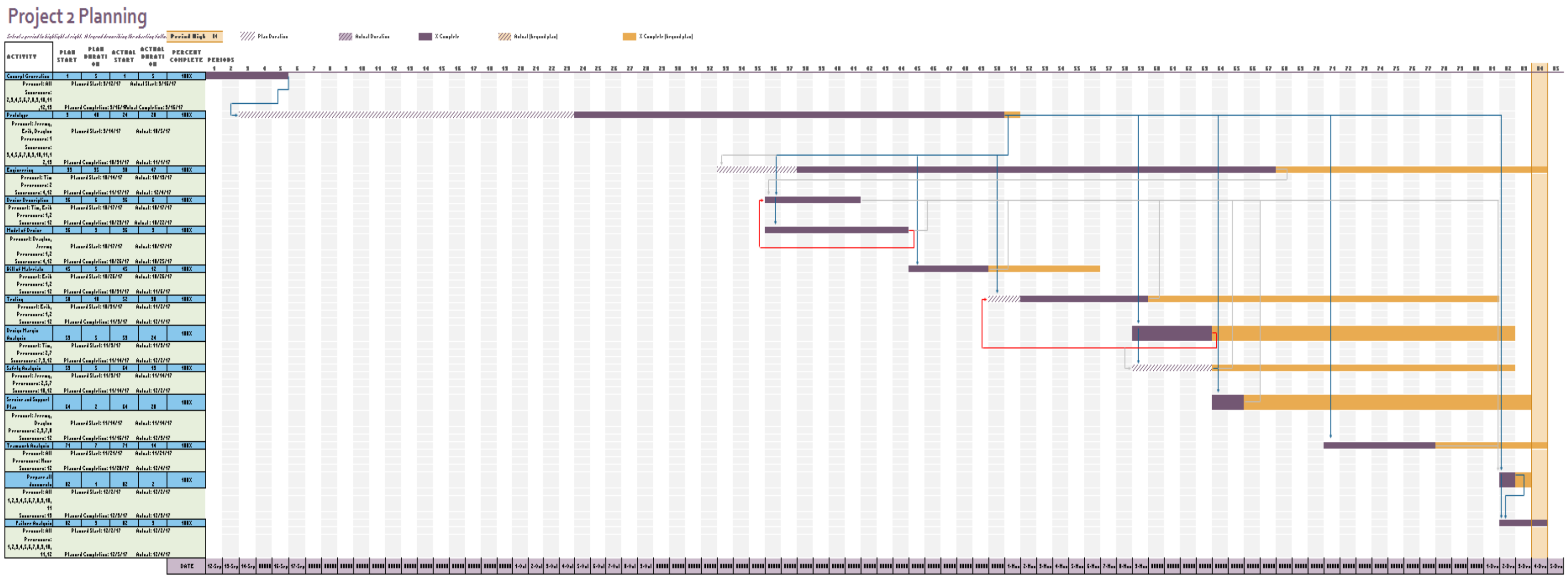


Fig. 1.13 – Week 13

## 2.) ***Specification Development***

| | Dr. Gadomski | MECH202 Group 2 | Competition Spectators | Demanded Quality (Customer Requirements) / Quality Characteristics (Functional Requirements) | Lift | Weight | Reliability | Setup Time | Cost | Footprint (Area) | Motor Operational Speed | Energy Capacity of Battery | Power Consumption | Quadcopter | Glider | Slingshot (Elastic) | Cannon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Units of Measure | N | lbs | % | sec | $ | in^2 | RPM | mAh | W | | | | |
| | | | | Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X) | ▲ | ▼ | ▲ | ▼ | ▼ | ▼ | ▲ | ▲ | ▼ | | | | |
| 1 | 5 | 10 | 0 | Durable | | 25% | 75% | | | | | | | 3 | 3 | 5 | 3 |
| 2 | 20 | 20 | 25 | Reliable Performance | | | 75% | | | | | | 25% | 3 | 3 | 4 | 2 |
| 3 | 20 | 10 | 0 | Low Weight | | 100% | | | | | | | | 3 | 3 | 5 | 1 |
| 4 | 20 | 10 | 0 | Meets Area Requirement | | | | | | 100% | | | | 5 | 5 | 5 | 5 |
| 5 | 20 | 15 | 50 | Won't Injure Operators/ Spectators | | | 100% | | | | | | | 4 | 4 | 4 | 1 |
| 6 | 10 | 15 | 25 | Travels a Long Distance | 25% | | | | | | 25% | 25% | 25% | 3 | 3 | 4 | 5 |
| 7 | 0 | 10 | 0 | Easily Servicable | | | | 100% | | | | | | 3 | 4 | 5 | 1 |
| 8 | 5 | 10 | 0 | Low Cost | | | | | 100% | | | | | 5 | 5 | 5 | 3 |
| | | | | Importance Customer 1 | 2.5 | 21.25 | 38.75 | 0 | 5 | 20 | 2.5 | 7.5 | 7.5 | | | | |
| | | | | Importance Customer 2 | 3.75 | 12.5 | 37.5 | 10 | 10 | 10 | 3.75 | 3.75 | 8.75 | | | | |
| | | | | Importance Customer 3 | 6.25 | 0 | 68.75 | 0 | 0 | 0 | 6.25 | 6.25 | 12.5 | | | | |
| | | | | Target (Delighted) | 8.9 | 1 | 95 | 8 | 0 | 50 | 10000 | 1500 | 100 | | | | |
| | | | | Target (Disgusted) | 4.5 | 2 | 83 | 45 | 200 | 192 | 5000 | 750 | 50 | | | | |

Customer | Competitive Analysis (0 = Worst, 5 = Best): 1 2 3 4 5

Fig. 2.1 – QFD Chart

**QFD Analysis:**

Customer Requirements:

| | Dr. Gadomski | MECH202 Group 2 | Competition Spectators | Demanded Quality (Customer Requirements) |
|---|---|---|---|---|
| 1 | 5 | 10 | 0 | Durable |
| 2 | 20 | 20 | 25 | Reliable Performance |
| 3 | 20 | 10 | 0 | Low Weight |
| 4 | 20 | 10 | 0 | Meets Area Requirement |
| 5 | 20 | 15 | 50 | Won't Injure Operators/ Spectators |
| 6 | 10 | 15 | 25 | Travels a Long Distance |
| 7 | 0 | 10 | 0 | Easily Servicable |
| 8 | 5 | 10 | 0 | Low Cost |

Fig. 2.2 – Customers & Requirements

*Durable* – The device must be able to withstand some impact forces so as to not be made unusable.

*Reliable Performance* – If the device cannot yield consistent results, then the customers will not value the device as highly then if it were to consistently perform. The customers want to see the device work every time.

*Low Weight* – The specifications listed in the project requirements say that the device must fall within a certain weight range.

*Meets Area Requirement* – The device must fall within a certain area. If it does not fall within this area range, the customers will not be pleased since it will not be able to compete.

*Won't Injure Operators/ Spectators* – It is important for the device to not cause injuries to any of the people who will be operating or viewing the device as it attempts to participate in the competition. If the device were to cause harm to anybody, all of the customers would be very displeased.

*Travels a Long Distance* – One of the primary goals for this device is for it to travel a long distance. By travelling a long distance, it has a greater chance of winning on competition day and will cause customers to be more excited about the product.

*Easily Serviceable* – If the device can't be easily serviced in the event of a malfunction or breakage, then this may result in the device missing out on testing time or competition rounds.

*Low Cost* – This project is not intended to incur a high cost, so it is important to keep the cost down. The customers want a product that is as cheap as possible while still maintaining a strong design.

<u>Customers</u>:

*Dr. Gadomski* – He is one of our customers since he is the one who is running the competition and will have a large influence over how our project will be graded. It is important to understand what he wants in order for us to succeed on the project and produce a device of high quality. Dr. Gadomski values reliable performance, low weight, area requirement, and the safety of operators/ spectators. These requirements must be met in order for the device to be able to compete in the competition.

*MECH202 Group 2* – Our design group is one of the customers since we are the ones who will be designing and producing a product for the project. We have a wide range of requirements that we must consider in order to create an effective device for the project. We value every requirement about equally, with more importance placed on reliability since if the device can't yield consistent results, we have a lower chance of succeeding.

*Competition Spectators* – The competition spectators generally care about seeing a device that can successfully travel a long distance. The also value not being injured in the process of viewing the competition. This is why they value travelling a long distance, safety of spectators, and reliability. Spectators don't care about the other requirements since they don't really impact the performance of the device during the competition.

<u>Engineering Specifications:</u>

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Units of Measure | N | lbs | % | sec | $ | in^2 | RPM | mAh | W |
| Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X) | ▲ | ▼ | ▲ | ▼ | ▼ | ▼ | ▲ | ▲ | ▼ |
| Quality Characteristics (Functional Requirements) / Demanded Quality (Customer Requirements) | Lift | Weight | Reliability | Setup Time | Cost | Footprint (Area) | Motor Operational Speed | Energy Capacity of Battery | Power Consumption |

Fig. 2.3 – Specifications

*Lift (N)* – Force to bring the weight of the device off of the ground. This was calculated using the weight of the device.

*Weight (lbs)* – This refers to the weight of the device.

*Reliability (%)* – This is the number of successful trials out of the total number of trials.

*Setup Time (sec)* – Time required to setup the device so it is able to be launched.

*Cost ($)* – Total cost incurred in the design and construction of the device.

*Footprint (in²)* – The area that the footprint of the device can be compressed down to.

*Motor Operational Speed (RPM*) – Revolutions per Minute of the motor. This value can be set using a speed controlling device.

*Energy Capacity of Battery (mAh)* – This is one of the specifications listed for a battery. The higher the value, the greater the amount of time that a battery can supply power.

*Power Consumption (W)* – Power consumed by the device to lift and propel it. A  greater power consumption requires a larger battery.

<u>Competitive Analysis</u>:

| Quadcopter | Glider | Slingshot (Elastic) | Cannon |
|---|---|---|---|
| 3 | 3 | 5 | 3 |
| 3 | 3 | 4 | 2 |
| 3 | 3 | 5 | 1 |
| 5 | 5 | 5 | 5 |
| 4 | 4 | 4 | 1 |
| 3 | 3 | 4 | 5 |
| 3 | 4 | 5 | 1 |
| 5 | 5 | 5 | 3 |

Fig. 2.4 – Competitive Analysis

*Quadcopter* – The most common setup for a small scale drone, a quadcopter has four rotors to lift and propel itself. The quadcopter met all of the customer requirements to a certain degree, but it can run into problems with durability, reliability, serviceability, and meeting the weight requirements while effectively propelling itself. The four rotors and propellers are all at risk of fracturing in the event of a collision. The coding that goes into programming a quadcopter to fly automatously over a long distance can be difficult to perfect, resulting in some reliability issues.

*Glider* – The glider also meets all of the requirements, but its design can pose some challenges too. The glider is dependent on there not being any stray breezes or other outside factors to throw it off course during its flight. Gliders can be more easily serviced than a drone, such as a quadcopter, since it is not required to have electronics on board a glider to make it fly.

Slingshot – A slingshot is simple to construct, service, and it doesn't cost too much to produce. A slingshot can be composed of just an elastic band and a projectile to be launched. Elastic bands are very common, so if one were to break, it can be easily replaced. One downside to consider when constructing a slingshot is that the elastic band can lose its tension potential after repeated stretching. This can result in inconsistent launches since the band may offer less force on release.

*Cannon* – A cannon, while easily capable of launching projectiles over long distances, does not offer the same level of safety and serviceability as the other competitors. Due to these factors, a cannon is not really a choice for this project.

<u>Target Values</u>

*Lift:*

> *Delighted (8.9 N)* – The maximum allowable weight for this project is two pounds, so it takes 8.9 newtons to lift two pounds.
>
> *Disgusted (4.5 N)* – Half of the delighted value was chosen as a suitable disgusted value.

*Weight*

*Delighted (1 lb)* – Half of the maximum allowable weight for this project was chosen as the delighted value.

*Disgusted (2 lb)* – Two pounds is the maximum allowable weight for this project. Any more and the device will not be allowed to compete.

*Reliability*

*Delighted (95%)* – A high reliability is necessary to be able to win the competition. 100% is ideal but not realistic for this project.

*Disgusted (83%)* – In order to win the competition, a group must win at least six rounds in a row. 83% was the calculated number for winning six consecutive rounds.

*Setup Time*

*Delighted (8 sec)* – From viewing other groups setting up their own devices, 8 seconds was about the average time it took for groups to setup.

*Disgusted (45 sec)* – A group is allowed 45 seconds to setup their device before they have to launch in the competition.

*Cost*

*Delighted ($0)* – Ideally, this project shouldn't cost anything.

*Disgusted ($200)* - $200 is the maximum cost recommended for this project.

*Footprint (Area)*

*Delighted (50 $in^2$)* – 50 inches was chosen as the delighted value.\

*Disgusted (192 $in^2$)* – 192 square inches is the maximum allowable area for the dimensions given (8x24 inches).

*Motor Operational Speed*

*Delighted (10000 rpm)* – 10000 rpm was the value that we used in determining the necessary thrust that we would need to produce with two propellers to lift two pounds.

*Disgusted (5000 rpm)* – 50% of the delighted rpm value was used as the disgusted value.

*Energy Capacity of Battery*

*Delighted (1500 mAh)* – 1500 mAh was used since that was the specific batteries that were available to the group. Batteries commonly have between 1000 and 2500 mAh for small scale drone projects.

*Disgusted (750 mAh)* – 50% of the delighted value was used for the disgusted value.

*Power Consumption*

*Delighted (100 W)* – 100 W is roughly the necessary power required to drive a 6x4 propeller to the calculated thrust value.

*Disgusted (50 W)* – Half the delighted value was used for the disgusted value.

### 3.) Engineering Analysis

**Static Thrust Calculation**

$$Power = Prop\ Const * rpm^{power\ factor}$$

$$Power = 0.060 * 10^{3.20} = 95.1\ W$$

Propeller constants and power factors for the 8X4 propeller was found at (2), power (P) is in Watts, and rpm is divided by 1000. The calculation above uses 10,000 rpm.

$$T = \frac{\pi}{8} D^2 \rho (\Delta v)^2$$

$$P = \frac{T\Delta v}{2} \rightarrow \Delta v = \frac{2P}{T}$$

$$T = \left(\frac{\pi}{2} D^2 \rho P^2\right)^{\frac{1}{3}}$$

Torque is found given the equation above where D is propeller diameter in meters, $\rho$ is air density, and P is power which was calculated above.

$$T = \left(\frac{\pi}{2}(0.2032\ m)^2 \left(1.225\frac{kg}{m^3}\right)(95.1\ W)^2\right)^{\frac{1}{3}} = 8.96\ N * m$$

The torque value which was found above is not very useful relating to our specifications so below the torque force is converted to a mass value. The value below is the mass that one motor equipped with an 8x4 propeller is capable of suspending in the air.

$$m = \frac{T}{g} = \frac{8.96\ N*m}{9.81\frac{m}{s^2}} = 0.913\ kg = 2.013\ lbs$$

The mass value found above shows that the device will be more than capable of leaving the ground using an 8x4 propeller since the device only weighs 1.26 lbs. and is equipped with two motors with 8x4 propellers.

***Mass Estimate***

| Table 3.1 – Mass Estimate |
|---|

| Number Required | Part | Weight (g) |
|---|---|---|
| 2 | DC Motor | 60.30 |
| 2 | ESC | 23.20 |
| 1 | Arduino | 28.50 |
| 2 | IMU | 1.50 |
| 1 | Li-Po Battery | 190.00 |
| 1 | Frame | 80.00 |
| 2 | Propeller | 20.00 |
| 2 | Servo | 10.80 |
| 1 | | 47.00 |
| | | 577.1 |

All parts included in the final device are shown above including individual masses of each component. The total mass was 0.577 kg is approximately 1.26 lbs. This mass is well below the thrust mass found in the previous section therefor no problems will arise concerning weight and lift forces.

***Flight Time***

$$flight\ time = \frac{Battery\ capacity}{amps}$$

$$flight\ time = \left(1500mAh\left(\frac{60min}{hr}\right)\left(\frac{1}{6A}\right)\left(\frac{1A}{1000mA}\right)\right) = 15\ min$$

Using the equation above flight time was found to be 15 minutes with the 11.1V 1500mAh battery paired with 1000kV motors 8x4 propellers and 30A ESC controllers. The current value was found when the motors were tested a full speed on a digital power supply, each motor drew 3 Amps at full speed. Fifteen minutes is sufficient flight time since the competition consists of several short flights this battery will be effective in powering the device.

***PID Control Calculations***

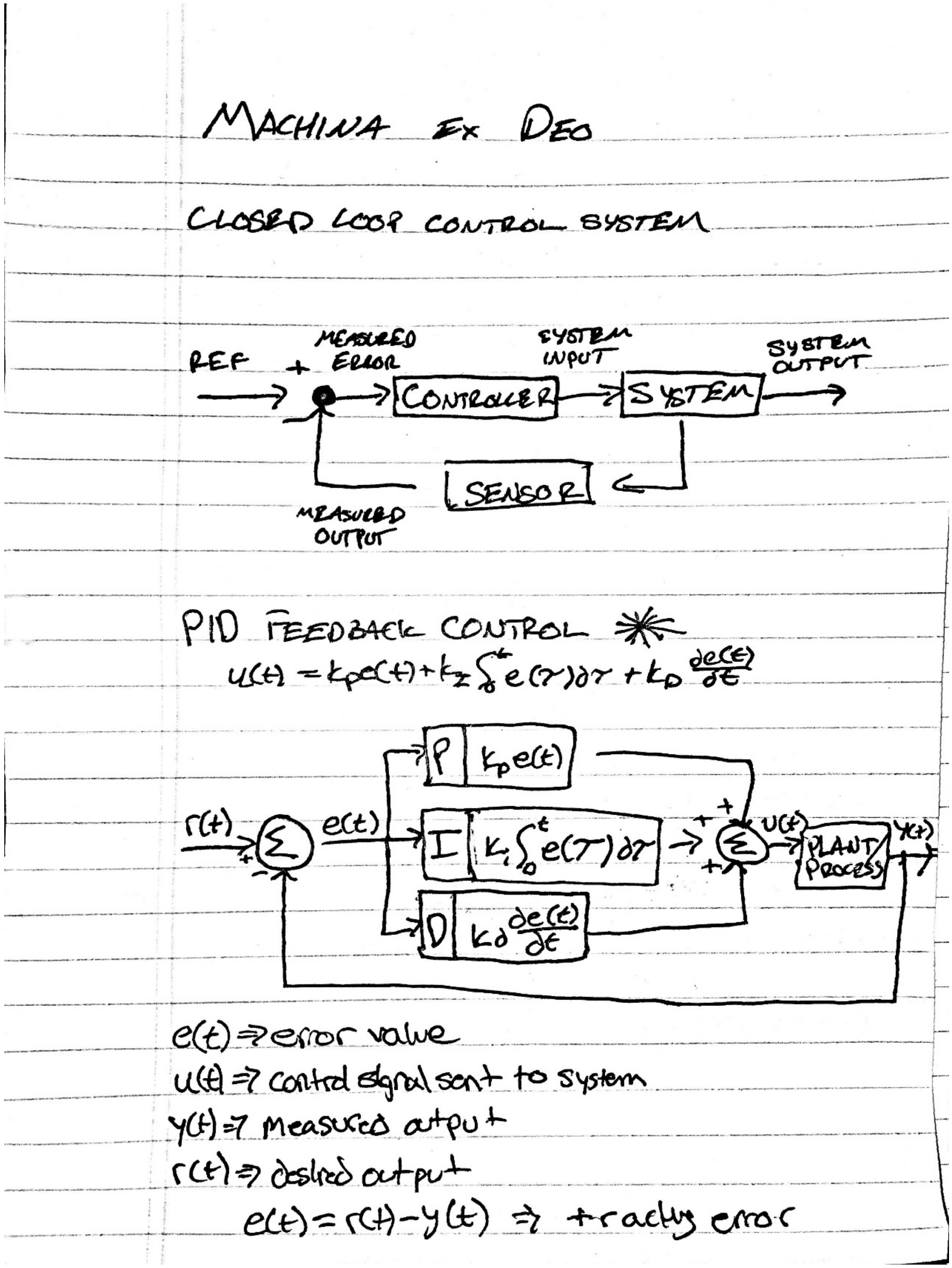


Figure 3.1 – PID Calculation

MPU-6050 $I^2C$ ONLY

Serial Ports

↳ asynchronous

↳ no clock data transmitted

1 start bit & 1 end bit needed

actual data bits = total bits − 2 :(

* TWO DEVICES MUST AGREE ON BAUD RATE

• SPI IS GOOD FOR HIGH DATA RATE FULL-DUPLEX

$I^2C$

• ONLY REQUIRES 2 WIRES

↳ 1008 SLAVES

• 2 signals

↳ SCL ⇒ clock signal

↳ SDA ⇒ data signal

* EACH SIGNAL LINE HAS A PULL-UP RESISTOR TO RESTORE SIGNAL HIGH WHEN NO DEVICE IS ASSERTING LOW (4.7k is good to start)

• $I^2C$ BUS DRIVERS ARE "OPEN DRAIN" ⇒ CAN PULL LINE LOW BUT CANNOT DRIVE HIGH

* IF 2 devices are on different voltage (5V + 3.3V) put pull-up resistors on lower voltage line

Figure 3. – PID Calculation

## *4) Concept Generation and Concept Selection*

Morphological table:

Table 4.1 – Morphology Table

| Morphology | | | |
|---|---|---|---|
| Product: EPAND | Organization Name : Group #2 | | |
| Function | Concept 1 | Concept 2 | Concept 3 |
| Propulsion | Propeller ** | Gravity * | Elastic |
| Stability | Wings * | Accelerometer ** | Frame |
| Durability | Foam * | Wood | Plastic ** |
| Lift | Propeller ** | Use Ramp * | Helium Balloon |
| Accuracy | Sensors ** | Accelerometer | Timer * |
| Automation | Button * | Arduino ** | Sensor |
| Landing | Parachute | Shock Absorber * | Propeller ** |
| Team member: Drayton Browning | Team member: Tim Roberts | Prepared by: Erik Pranckh | |
| Team member: Jeremy Tabke | Checked by: Tim Roberts | Approved by: Drayton Browning | |
| *The Mechanical Design Process* by Professor David G. Ullman<br>Copyright 2008, McGraw Hill 15.0 | | | Designed<br>Form # |

| |
|---|
| ** = First choice |
| *= Second choice |

Brain Writing (6-3-5 Method):

Table 4.2 – Brain writing

| How to launch device across gym | Ideas |
|---|---|
| Person 1 | Coaxial Mono-copter |
| | Solar Sail |
| | Rubber Band Powered Plane |
| Person 2 | Hover Craft |
| | Water Powered Jet Pack |
| | Steam Plane |
| Person 3 | Glider |
| | Trained Bird |
| | Blimp |
| Person 4 | Railgun |
| | Mouse Trap |
| | Quad-Copter |

Although we only had four group members we thought the 6-3-5 method would be a beneficial concept generation tactic. Each of the four group members wrote down three design concepts in five minutes. The group completed three five minute rounds using this method, after identical designs were filtered through each member selected their three best concepts which are seen above in (Table 4.2).

Brain Mapping:

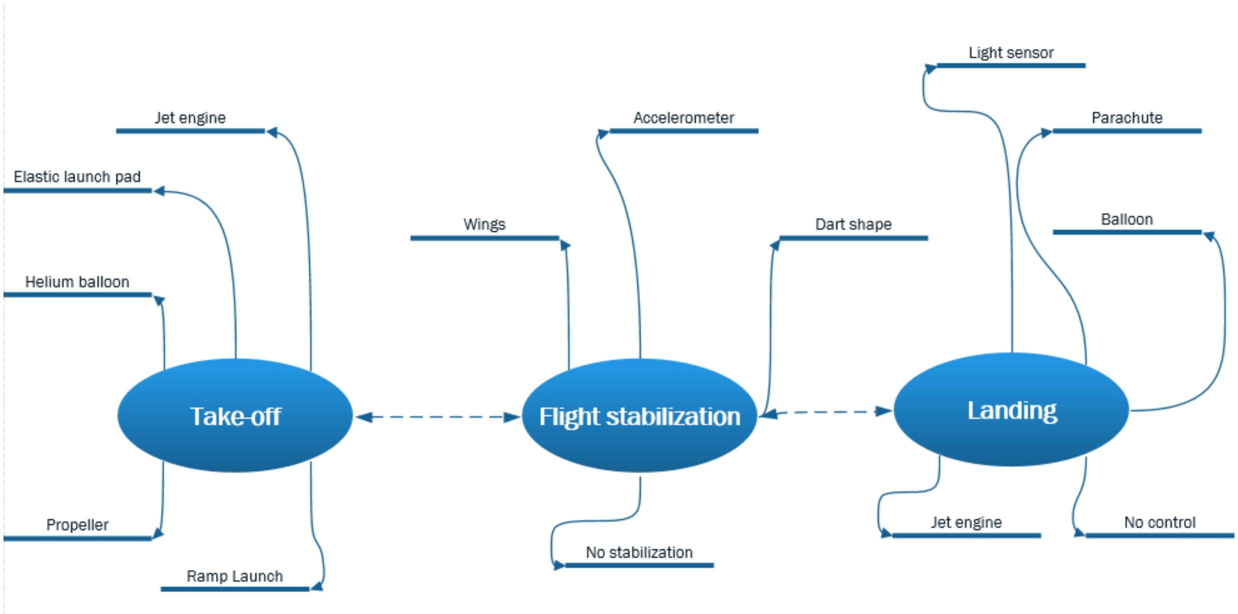


Figure 4.1 – Brain mapping

Starting with the three most critical functions of our device the group brainstormed several ways to achieve the necessary function. The brain map diagram seen above shows the ideas generated to achieve lift, stabilization, and landing.

**Functions:**

*Take Off/Lift*

- The ability to elevate from the ground and clear ramp.

*Flight/Stabilization*

- The ability to achieve controlled flight and travel through the air without making contact with the ground for a determined distance.

*Landing/Decent*

- The ability to make a controlled landing so as not to damage device or floor.

Table 4.3 – Lift

| Take Off/Lift<br>Issue: Elevate and clear ramp. | | **Base: Propeller** | Ramp Launch | Helium Balloon | Jet engine | Elastic Launch |
|---|---|---|---|---|---|---|
| Mass efficiency | 30 | 0 | 1 | 1 | -1 | 0 |
| Ease of integration | 20 | 0 | 1 | 1 | -1 | 1 |
| Cost effective | 10 | 0 | 1 | 0 | -1 | 1 |
| Reliability | 20 | 0 | -1 | 1 | -1 | 0 |
| Size | 20 | 0 | 0 | -1 | -1 | 0 |
| | Total: | 0 | 2 | 2 | -5 | 2 |
| | Weighted Total: | 0 | 40 | 50 | -100 | 30 |

Table 4.4 – Flight

| Flight/Stabilization<br>Issue: Achieve controlled flight autonomously for required distance. | | **Base: Accelerometer** | Wings | No Stabilization | Jet engine | Dart |
|---|---|---|---|---|---|---|
| Mass efficiency | 25 | 0 | 0 | 1 | -1 | 1 |
| Ease of integration | 15 | 0 | -1 | 1 | 0 | 1 |
| Cost effective | 10 | 0 | 1 | 1 | -1 | 1 |
| Reliability | 30 | 0 | -1 | -1 | -1 | 1 |
| Size | 20 | 0 | -1 | 1 | -1 | 1 |
| | Total: | 0 | -2 | 3 | -4 | 5 |
| | Weighted Total: | 0 | -55 | 40 | -85 | 100 |

Table 4.5 – Decent

| Landing/Decent<br>Issue: Make a controlled landing without sustaining damage. | | **Base: Light Sensor** | Parachute | Helium Balloon | Jet engine | No Control |
|---|---|---|---|---|---|---|
| Mass efficiency | 40 | 0 | 1 | 0 | -1 | 1 |
| Ease of integration | 10 | 0 | 0 | 1 | 0 | 1 |
| Cost effective | 10 | 0 | 1 | 0 | -1 | 1 |
| Reliability | 25 | 0 | 0 | 0 | 0 | -1 |
| Size | 15 | 0 | 1 | -1 | -1 | 1 |
| | Total: | 0 | 3 | 0 | -3 | 3 |
| | Weighted Total: | 0 | 65 | -5 | -65 | 50 |

***<u>Take Off/Lift Belief Map:</u>***

| | |
|---|---|
| Propeller | |
| Ramp Launch | |
| Helium balloon | |
| Jet Engine | |
| Elastic Launch | |

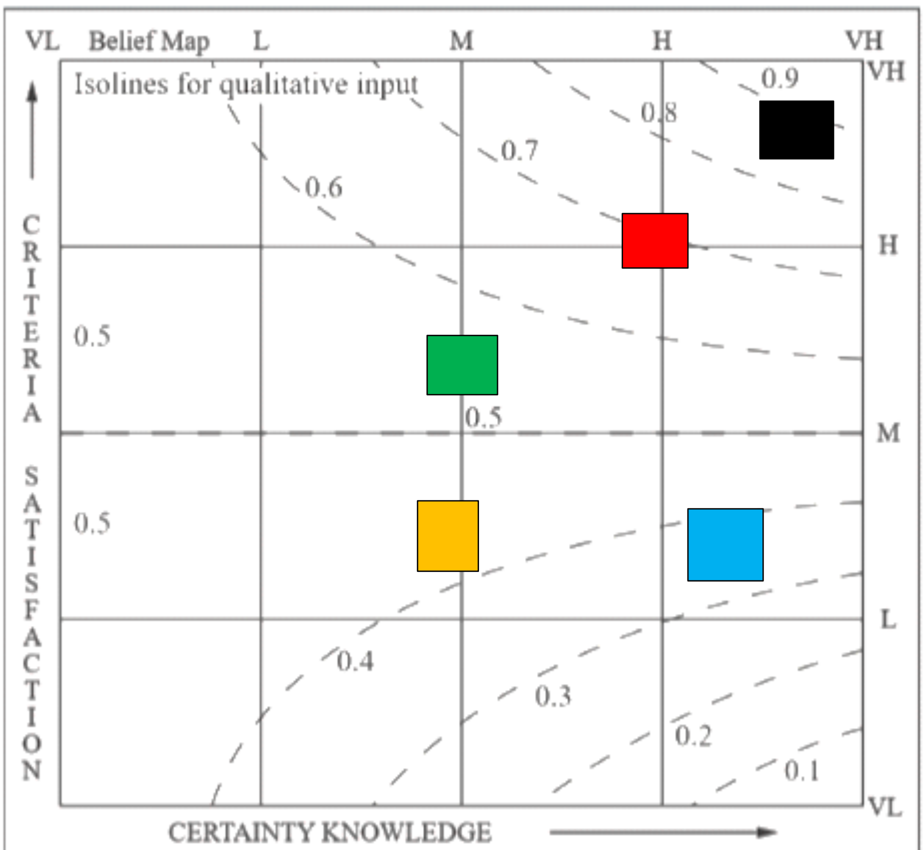


Figure 4.2 – Belief Map

***Flight/Stabilization***

| | |
|---|---|
| Accelerometer | |
| Wings | |
| No Stabilization | |
| Jet Engine | |
| Dart | |

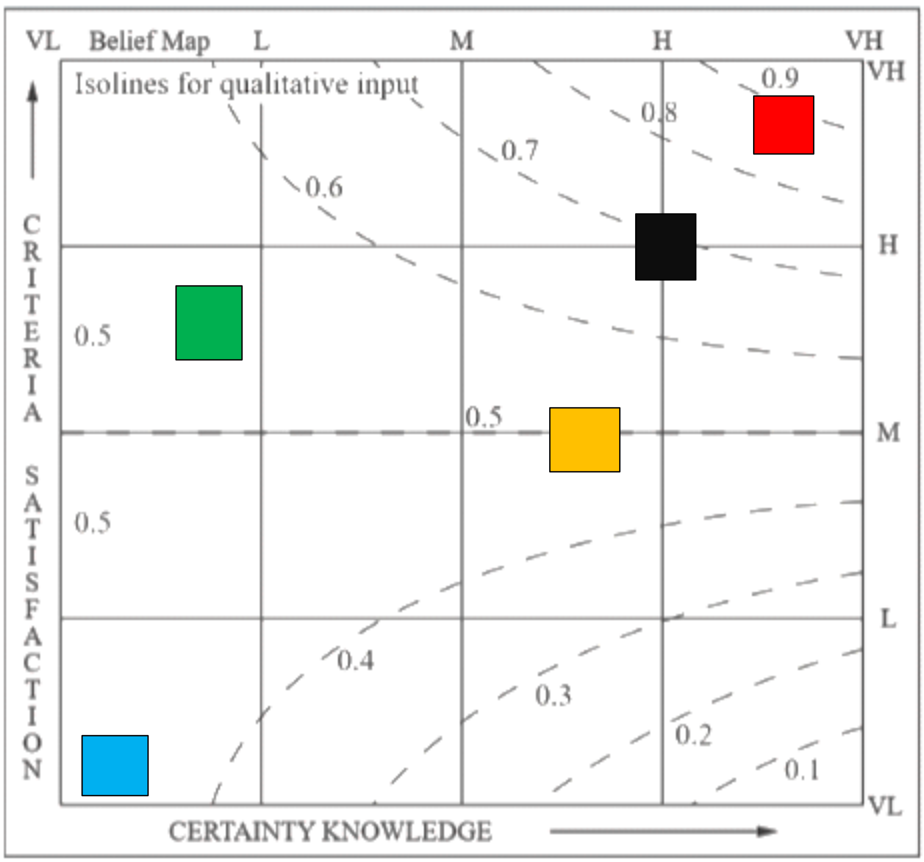


Figure 4.3 Belief map

***Landing/Descent***

| | |
|---|---|
| Light Sensor | |
| Parachute | |
| Helium balloon | |
| Jet Engine | |
| No Control | |

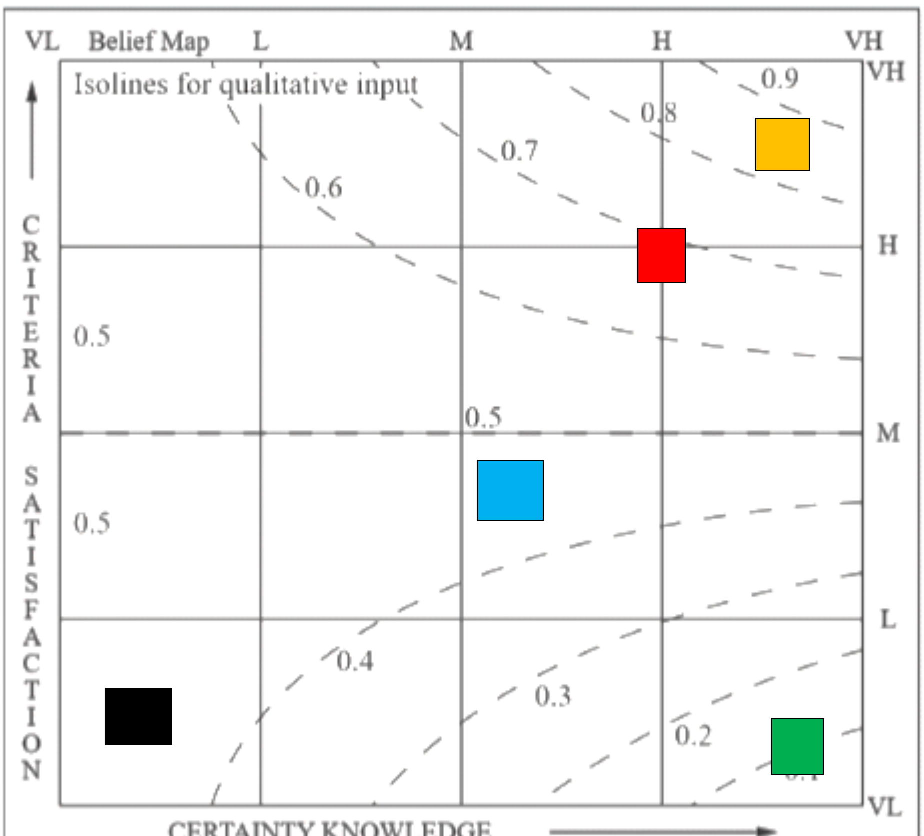


Figure 4.4 – Belief map

Pugh's analysis of DC motors and propellers

There are three types of motors that are typically used for small drone construction: Brushed, brushless inrunner, and brushless outrunner. Brushed motors work by having a power source connected to small tabs (brushes) which brush up against a plate inside of the motor, causing a charge to be transferred. These induced poles have opposite charges, causing the motor to rotate due to the attraction and repulsion of the poles. The difference between brushless and brushed motors is that brushless motors have stationary "tabs," or poles. The permanent, powered magnet of the motor remains stationary, unlike in brushed motors.

Inrunner motors have the permanent magnet on the inside of the tabs while outrunners have the permanent magnenets on the outside. This results in some differences in performance:

Table 4.6 – Pughs

| Issue: Compare different motors | Importance | Brushless Inrunner | Brushless Outrunner | Brushed |
|---|---|---|---|---|
| RPM | 20 | DATUM | 0 | -1 |
| Torque | 15 | | 1 | 0 |
| Efficiency | 25 | | -1 | -1 |
| Power Consumption | 25 | | 0 | -1 |
| Maintenance | 15 | | 1 | -1 |
| | | Total: | 1 | -4 |
| | | Weighted Total: | 5 | -85 |

Brushed motors aren't preferred since the process of the brushes rubbing against the magnet results in a loss of power due to friction and it causes the motor to wear down more quickly.

Even though inrunner motors can produce a higher rpm, the rpm that can be produced by the inrunner is more than adequate for powering propellers for a light weight drone. Both the brushless outrunner and brushless inrunner motor will work for our project, so it really doesn't matter too much which type of brushless motor we use.

Given that we decided to use 8 inch diameter, 4 inch pitch propellers (8x4), we then needed to decide how many blades to use. Looking at some real world examples, larger aircraft tend to use more propeller blades, while smaller drones and RC toys usually use fewer blades. This is because having more blades produces more torque. Having more blades does mean that more power must be consumed, as shown in this formula:

$$P_2 = P_1(\frac{B_2}{B_1})$$

Where P is power consumption, B is number of blades, $B_2$ is an increased number of blades, and assuming we use identical blades (same diameter, pitch, and shape).

The following Pugh's table shows the comparison between a few different types of 8x4 propellers:

Table 4.7 – Pugh's

| Issue: Compare 8 inch diameter 4 inch pitch propellers (8x4) | Importance | 2-Blade Propeller (8x4x2) | 3-Blade Propeller (8x4x3) | 4-Blade Propeller (8x4x4) |
|---|---|---|---|---|
| Propulsion | 12.5 | DATUM | 1 | 1 |
| Stabilization | 15 | | 1 | 1 |
| Lift | 15 | | 1 | 1 |
| Durability | 5 | | 0 | 0 |
| Power Consumption | 17.5 | | -1 | -1 |
| Efficiency | 20 | | -1 | -1 |
| Weight | 15 | | -1 | -1 |
| | Total: | | 0 | 0 |
| | Weighted Total: | | -10 | -10 |

Increasing the number of blades proved to not be necessary for our design, since we do not require a greater lift and propulsion at the cost of decreased efficiency and increased power consumption. Lift and propulsion provided by two blades is more than enough to lift and propel two pounds.

## ***5) Device Description***

Overall Device Function:

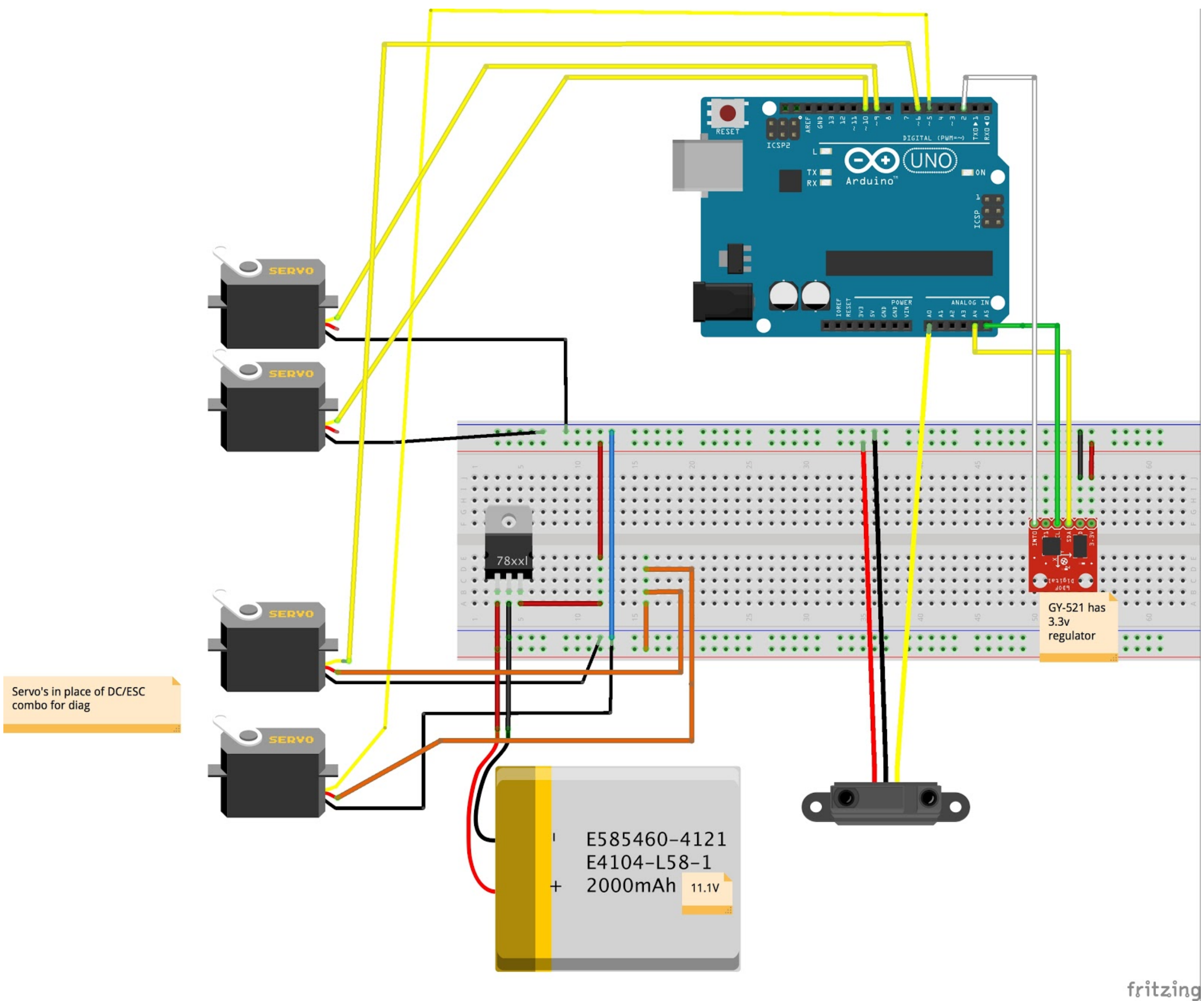


Figure 5.1 – Wiring Diagram

The Bi-Copter is powered with the Arduino as the microcontroller receiving signals from the IR sensor for distance measurements and from the MPU-6050 for device angle measurements. The microcontroller then uses these signals to send commands to the ESC to modulate the pulses sent the motors, and angle commands to the servo for leveling.

<u>Design Development:</u>

Due to the complexity of this device there were a number of changes made to the overall design to optimize function. Incorporating the many components of the device into a light weight chassis proved to be quite challenging.

The most important feature of the chassis was designing an interface between the chassis and the servo controlled motors. The servo had to be fixed such that it could support not only itself but also the force of the motor during flight and rest. The first option was to mount the servo in such a way that it did not support the weight of the motor at all and just controlled movement. The initial model of this design is shown in the image below (Figure 5.2).

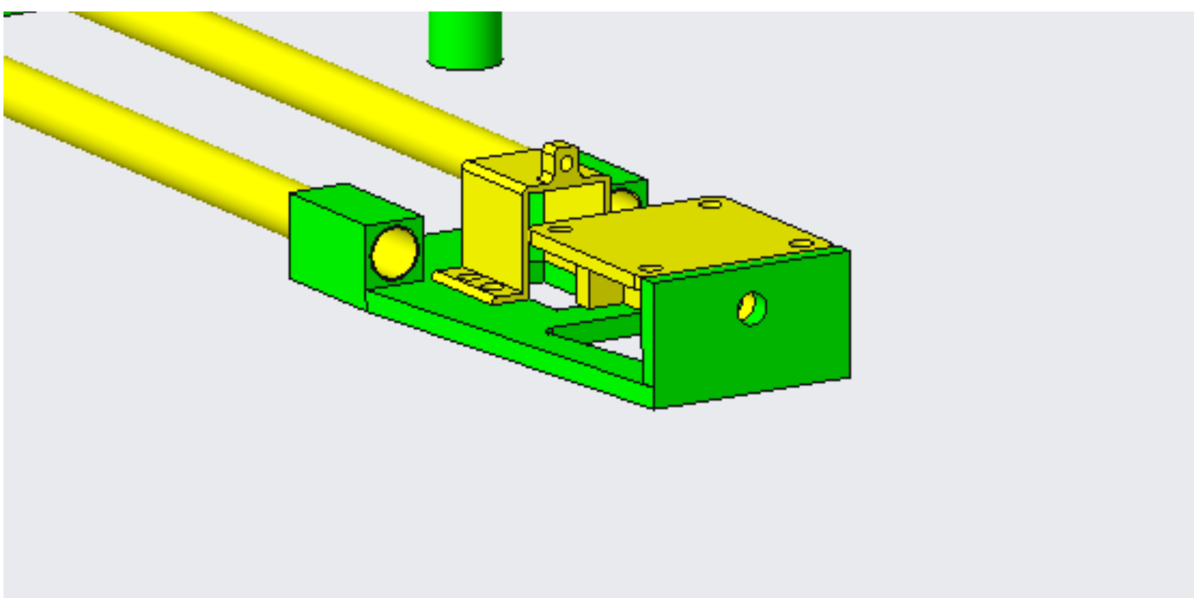

Figure 5.2 – Device Image

In this design the servo is fixed using a thin 3D printed bracket and moves the motor mount on the horizontal axis. The motor mount is supported on both sides with a screw as an axle. This design did not prove to be effective due to the friction on the support axles and weak mounting location for the servo. The final iteration of the design shown in image below (figure 5.3) incorporated a more ridged servo mount and a motor mount that was supported by the servo alone.

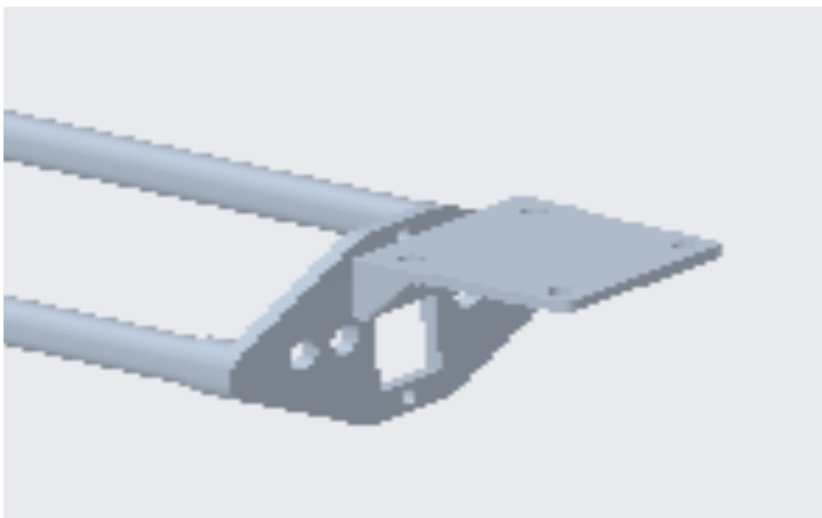

Figure 5.3 – Motor Mount

The new design supports the servo on all sides and has two mounting holes that fix it firmly in place. The motor mount is then attached directly to the servo which eliminates any external frictional forces.

The base was important because it would provide a mounting location for all of the electronic controls. In initial testing the electronic controls were not mounted to the device as it was not allowed to achieve flight. It became apparent that the initial concept to mount the base directly to the Extension Tubes, Shown in image below (Figure 5.4) would not be effective due to the high center of gravity and interference with the propellers.

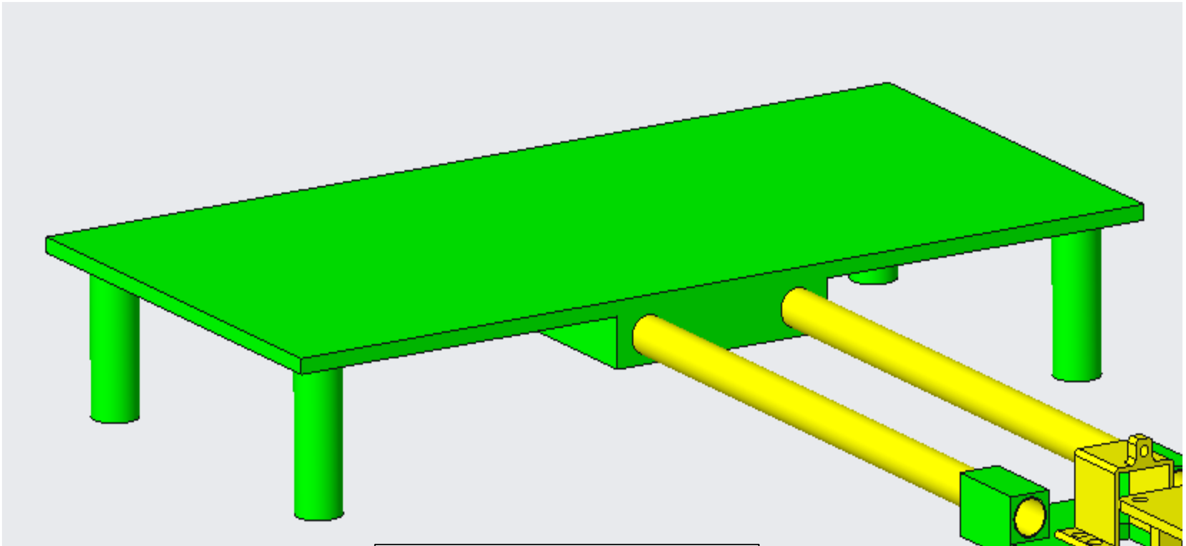

Figure 5.4 – Base

The Uniframe Support Skis, shown below (Figure 5.5), were designed to move the base below the Extension Tubes and lower the center of gravity.

Figure 5.5 – Support

Chassis:

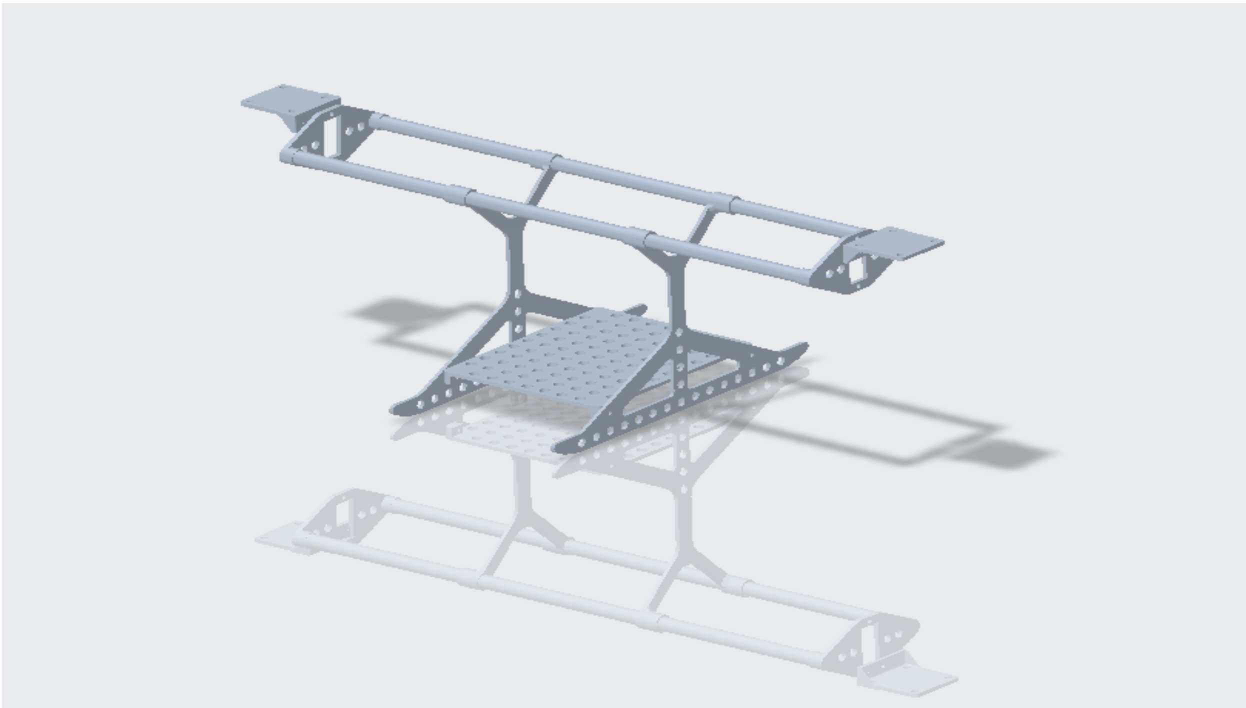

Figure 5.6 – Chassis

The chassis of the Bi-Copter pictured above (Figure 5.6) largely consists of printed PLA plastic parts, with the exception of the carbon fiber extension tubes (Part #11). 3D printing afforded an effective way to rapidly manufacture new parts as design improvements were made, without sacrificing the structural integrity of the final product. The chassis is assembled using generic fasteners.

*Part #11 Extension Tube*

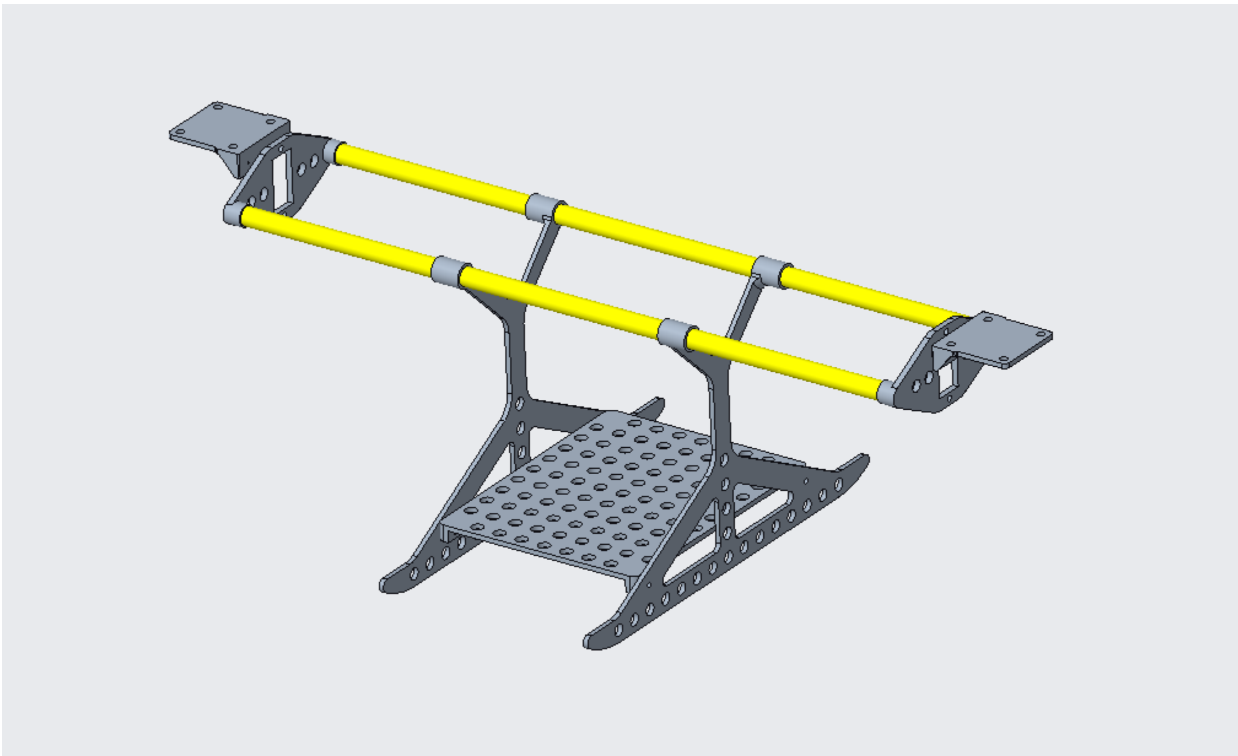

Figure 5.7 – Extensions

The Extension Tubes, highlighted yellow in the picture above (figure 5.7) are the back bone of the device. They provide structural rigidity while allowing the brushless motors to be adequately spaced apart so that the propellers do not interfere with each other. Carbon fiber was used for the extension tubes to minimize weight without sacrificing structural integrity. The carbon fiber was sourced from repurposed 7.6mm arrow shafts which eliminated any cost associated with using the stronger material.

*Part #9 Uniframe Support Skis*

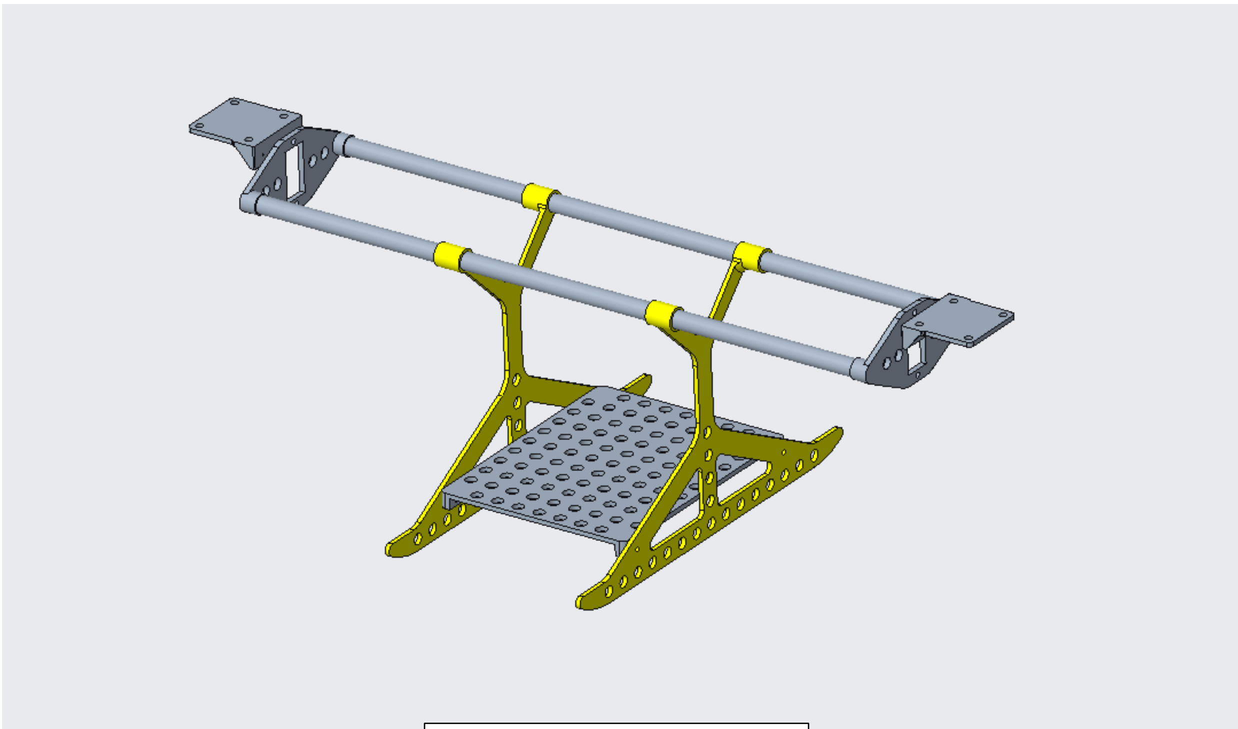

Figure 5.8 – Supports

The Uniframe Support Skis highlighted in yellow above (figure 5.8) provide a level surface to land and take off from. They also allow the base to be mounted further below the motors and thus lowering the center of gravity. The 2mm holes that run along the skis and up the main pillar serves both as weight reduction and routing locations for wiring. The Uniframe Support Skis are 3D Printed with gray PLA plastic.

*Part #10 Baseboard:*

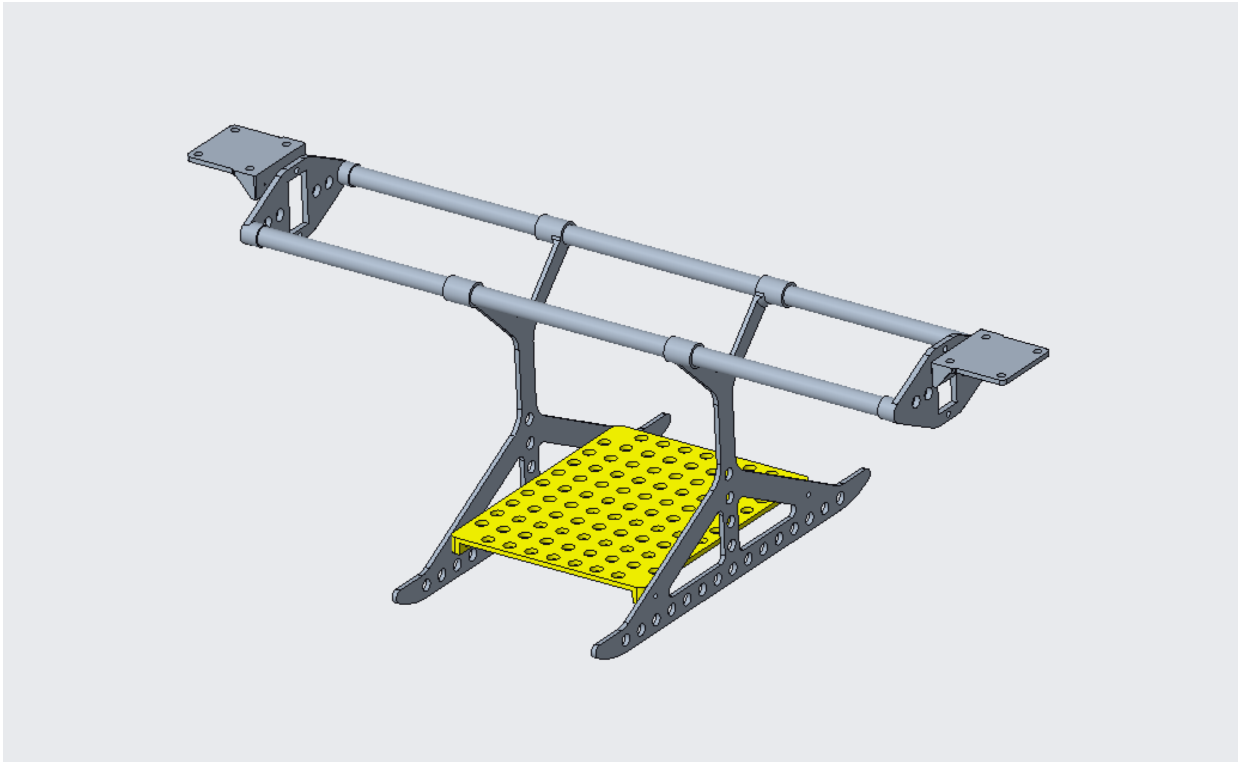

Figure 5.9 - Base

The Baseboard highlighted in yellow above (Figure 5.9) provides a mounting location for the breadboard and ArduinoThe Baseboard is designed with assorted mounting configurations to reduce weight and allow the device to be balanced properly. The Baseboard are 3D Printed with gray PLA plastic.

*Part #12 Servo Mount:*

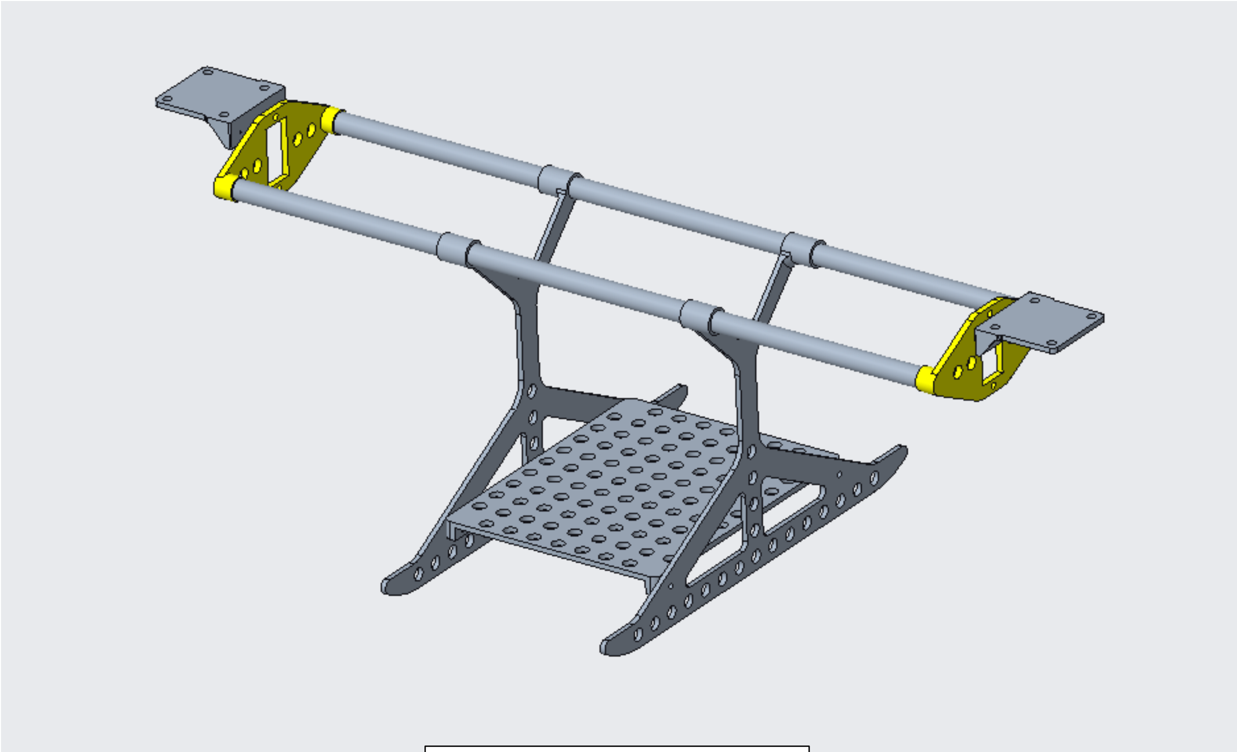

Figure 5.10 – Servo Mount

The Servo Mount highlighted in yellow above, (Figure 5.10) achieves a ridged mounting location for the servo, as well as providing additional stability to the frame. It is mounted with the extrusion facing inward to the Extension Tubes (Part #11) utilizing the two 7.7mm holes. The servo unit (Part #8) passes through the square cutout and is fixed with two self-taping screws. The four circular cutouts on either side of the square cutout serve to reduce overall weight of the part. The Servo Mount is 3D printed using gray PLA plastic

*Part #13 Motor Mount:*

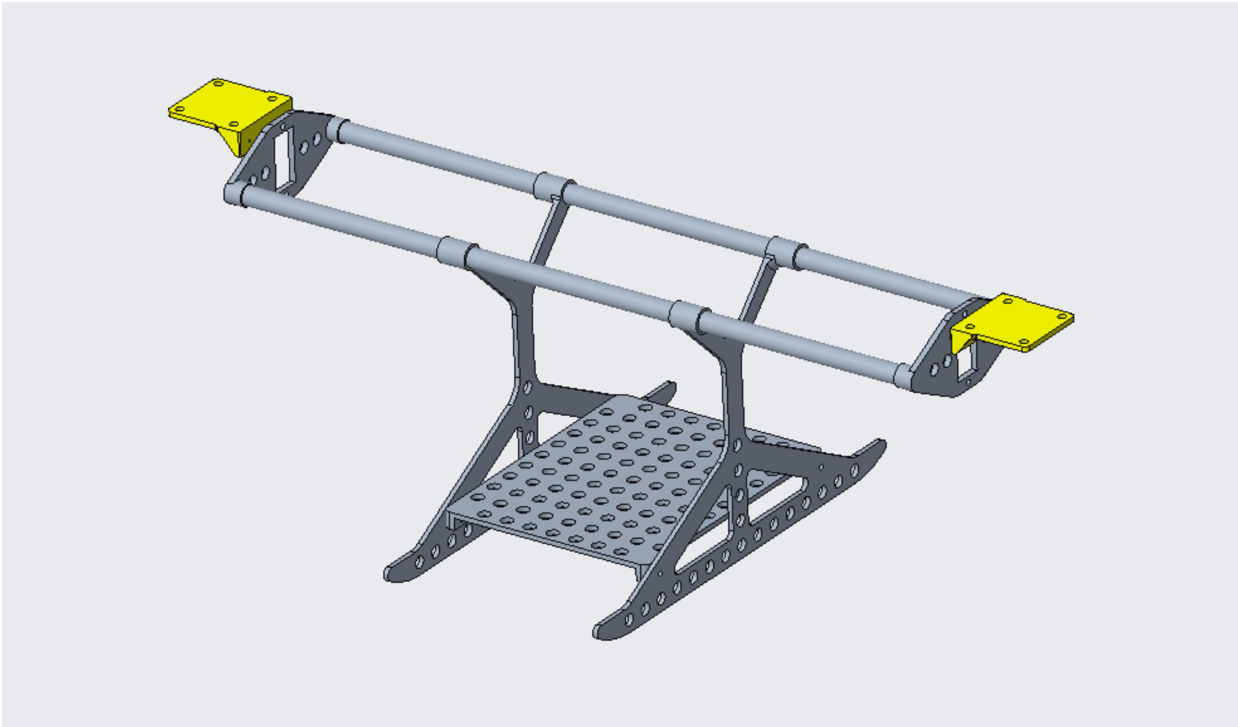

Figure 5.11 – Motor Mount

The Motor Mount highlighted in yellow above (Figure 5.11) provides a vertical mounting location for the brushless DC motor. It attaches directly to the Servo (Part #8) horizontally to so that the motor can be rotated forwards and backwards to control flight direction. It is designed to be both ridged and light weight to reduce strain on the servo. The Servo Mount is 3D printed using gray PLA plastic

<u>Power Train</u>:

The Bi-Copter power train consists of two opposing pitch propeller blades paired with brushless DC motors. These are powered by a 3 Cell Lipo battery pack. The Bi-Copter power train consists of the propellers, the 3-phase brushless DC motors, electronic speed controllers, and an Arduino. Two opposing pitch propeller blades spinning in CW and CCW rotation for moment balance. Two 3-phase brushless DC motors receive pulses generated from the ESCs which are controlled by the Arduino. These are all powered by a 3 Cell 11.1V Lipo battery pack.

Automated Control

The code for the flight controller was written using PlatformIO IDE on Visual code studio and makes use of the MPU6050 library created by Jeff Rowberg. The controller uses a closed loop proportional, integral, derivative feedback controller (PID). The MPU-6050 6DOF IMU was used for measurements during flight in order to calculate the error between the desired angle of the device and the actual angle. A Sharp GP2Y0A21YK infrared sensor was used to sense when the device was flying close in order to turn off the propellers to mitigate any damage upon impact.

The code is as follows:

```
#include "Servo.h"
#include "I2Cdev.h"
#include "MPU6050_6Axis_MotionApps20.h"
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
  #include "Wire.h"
#endif
#define OUTPUT_READABLE_YAWPITCHROLL
bool dmpReady = false;  // set true if DMP init was successful
uint8_t mpuIntStatus;   // holds actual interrupt status byte from MPU
uint8_t devStatus;      // return status after each device operation (0 = success, !0 = error)
uint16_t packetSize;    // expected DMP packet size (default is 42 bytes)
uint16_t fifoCount;     // count of all bytes currently in FIFO
uint8_t fifoBuffer[64]; // FIFO storage buffer

// orientation/motion vars
Quaternion q;           // [w, x, y, z]         quaternion container
VectorInt16 aa;         // [x, y, z]            accel sensor measurements
VectorInt16 aaReal;     // [x, y, z]            gravity-free accel sensor measurements
VectorInt16 aaWorld;    // [x, y, z]            world-frame accel sensor measurements
VectorFloat gravity;    // [x, y, z]            gravity vector
float euler[3];         // [psi, theta, phi]    Euler angle container
float ypr[3];           // [yaw, pitch, roll]   yaw/pitch/roll container and gravity vector
```

```
//Time and counter vars
float elapsedTime, time, timeprev;
int i;

//Arduino attatchments
MPU6050 mpu;
Servo servo_R;
Servo servo_L;
Servo R_esc;
Servo L_esc;
int servo_R_pin = 5;
int servo_L_pin = 6;
int R_esc_pin = 10;
int L_esc_pin = 9;
int ir_pin = A0;
int ir_value = 0;

//////PID//////

float desired_Yaw = 0;
float desired_Pitch = 0;
float desired_Roll = 0;
float error, prev_error, PID_Y, PID_P, PID_R, pwm_R, pwm_L;


//Yaw
float pid_p_Yaw_gain = 0;
float pid_i_Yaw_gain = 0;
float pid_d_Yaw_gain = 0;
int pid_max_Yaw = 180;//**************************************
double Y_kp = 0;
double Y_ki = 0;
double Y_kd = 0;



//Pitch
float pid_p_Pitch_gain = 0;
float pid_i_Pitch_gain = 0;
float pid_d_Pitch_gain = 0;
int pid_max_Pitch = 180;//**************************************
double P_kp = 0;
double P_ki = 0;
double P_kd = 0;
```

```
//Roll
float pid_p_Roll_gain = 0;
float pid_i_Roll_gain = 0;
float pid_d_Roll_gain = 0;
int pid_max_Roll = 2000;//**************************************
double R_kp = 3;
double R_ki = 0;
double R_kd = 0;

// ================================================================
// ===               INTERRUPT DETECTION ROUTINE                ===
// ================================================================

volatile bool mpuInterrupt = false;     // indicates whether MPU interrupt pin has gone high
void dmpDataReady() {
  mpuInterrupt = true;
}
void setup() {
// join I2C bus (I2Cdev library doesn't do this automatically)
  #if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
      Wire.begin();
      TWBR = 24; // 400kHz I2C clock (200kHz if CPU is 8MHz)
  #elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
      Fastwire::setup(400, true);
  #endif

Serial.begin(115200);
  while (!Serial); // wait for Leonardo enumeration, others continue immediately

//Set correct servo position for horizontal leveling
delay(500);
 R_servo.write(10);
 L_servo.write(10);
 delay(1000);
 R_servo.write(78);
 L_servo.write(55);
//Record Time
time = millis();

  // Attach motors
servo_R.attach(servo_R_pin);
servo_L.attach(servo_L_pin);
R_esc.attach(R_esc_pin);
L_esc.attach(L_esc_pin);
```

```
  //initialize device
mpu.initialize();
devStatus = mpu.dmpInitialize();
if (devStatus == 0) {
      // turn on the DMP, now that it's ready
      mpu.setDMPEnabled(true);

// enable Arduino interrupt detection
      attachInterrupt(0, dmpDataReady, RISING);
      mpuIntStatus = mpu.getIntStatus();

      // set our DMP Ready flag so the main loop() function knows it's okay to use it
      dmpReady = true;

      // get expected DMP packet size for later comparison
      packetSize = mpu.dmpGetFIFOPacketSize();
  }

// supply your own gyro offsets here, scaled for min sensitivity
  mpu.setXGyroOffset(142);
  mpu.setYGyroOffset(19);
  mpu.setZGyroOffset(21);
  mpu.setXAccelOffset(-2199);
  mpu.setYAccelOffset(-2547);
  mpu.setZAccelOffset(666);

//Arm ESC's
R_esc.writeMicroseconds(1000);
L_esc.writeMicroseconds(1000);
delay(7000);


}

void loop() {

 //Time
timeprev = time;
time = millis();
elapsedTime = (time - timeprev) / 1000; //In seconds

  // reset interrupt flag and get INT_STATUS byte
  mpuInterrupt = false;
  mpuIntStatus = mpu.getIntStatus();
```

```
  // get current FIFO count
  fifoCount = mpu.getFIFOCount();

  // check for overflow (this should never happen unless our code is too inefficient)
  if ((mpuIntStatus & 0x10) || fifoCount == 1024) {
     // reset so we can continue cleanly
 mpu.resetFIFO();
// otherwise, check for DMP data ready interrupt (this should happen frequently)
  } else if (mpuIntStatus & 0x02) {
     // wait for correct available data length, should be a VERY short wait
     while (fifoCount < packetSize) fifoCount = mpu.getFIFOCount();

     // read a packet from FIFO
     mpu.getFIFOBytes(fifoBuffer, packetSize);

     // track FIFO count here in case there is > 1 packet available
     // (this lets us immediately read more without waiting for an interrupt)
     fifoCount -= packetSize;
  }
      // display Euler angles in degrees
        mpu.dmpGetQuaternion(&q, fifoBuffer);
        mpu.dmpGetGravity(&gravity, &q);
        mpu.dmpGetYawPitchRoll(ypr, &q, &gravity);
        /*Serial.print("ypr\t");
        Serial.print(ypr[0] * 180/M_PI);
        Serial.print("\t");
        Serial.print(ypr[1]);
        Serial.print("\t");
        Serial.println(ypr[2] * 180/M_PI);
*/





pid_calculations ();

//R_esc.writeMicroseconds(pwm_R);
//L_esc.writeMicroseconds(pwm_L);
// Only send pulses to motors if IR sensor indicates that something is not infront of device
if (ir_value <= 50) {
 left_prop.writeMicroseconds(pwmLeft);
 right_prop.writeMicroseconds(pwmRight);
```

```
}
// If something is close to sensor send min pulse
else {
 left_prop.writeMicroseconds(1000);
 right_prop.writeMicroseconds(1000);
}
//timer when IR sensor is not in use
/*
else if ( time/1000 <= 15) {
 left_prop.writeMicroseconds(1300);
 right_prop.writeMicroseconds(1300);
}
*/

//Initiate forward tilt of servos for forward movement

if (time/1000 >= 10) {
 R_servo.write(73);
 L_servo.write(60);

prev_error = error;

}


///PID CALC///
void pid_calculations() {

//Yaw Calc
pid_p_Yaw_gain = Y_kp * error;
pid_i_Yaw_gain = pid_i_Yaw_gain + (Y_ki * error);
pid_d_Yaw_gain = Y_kd * ((error - prev_error)/elapsedTime);
PID_Y = pid_p_Yaw_gain + pid_i_Yaw_gain + pid_d_Yaw_gain;
if (PID_Y > 180){
   PID_Y = 180;
}
if (PID_Y < 0){
   PID_Y = 0;
}
servo_R.write(PID_Y);
servo_L.write(180 - PID_Y);

//Pitch Calc
pid_p_Pitch_gain = P_kp * error;
pid_i_Pitch_gain = pid_i_Pitch_gain + (P_ki * error);
```

```
pid_d_Pitch_gain = P_kd * ((error - prev_error)/elapsedTime);
PID_P = pid_p_Pitch_gain + pid_i_Pitch_gain + pid_d_Pitch_gain;
if (PID_P > 180){
  PID_P = 180;
}
if (PID_P < 0){
  PID_P = 0;
}
servo_R.write(PID_P);
servo_L.write(180 - PID_P);

//Roll Calc
pid_p_Roll_gain = R_kp * error;
pid_i_Roll_gain = pid_i_Roll_gain + (R_ki * error);
pid_d_Roll_gain = R_kd * ((error - prev_error)/elapsedTime);
PID_R = pid_p_Roll_gain + pid_i_Roll_gain + pid_d_Roll_gain;
if (PID_R > 2000){
  PID_R = 2000;
}
if (PID_R < 1000){
  PID_R = 1000;
}
pwm_R = PID_R;
pwm_L = -PID_R;
if (pwm_R > 2000){
  pwm_R = 2000;
}
if (pwm_R < 1000){
  pwm_R = 1000;
}
if (pwm_L > 2000){
  pwm_L = 2000;
}
if (pwm_L < 1000){
  pwm_L = 1000;
}
```

***6) Bill of Materials***

| Table 6.1– BOM | Bill of Materials |
|---|---|
| Product : MECH 202 Project 2 | Date: 12/3/17 |
| Assembly: EPAND | |

| Part # | Qty | Name | Description | Material | Manufacturing Process | Cost ($) |
|---|---|---|---|---|---|---|
| 1 | 1 | Arduino Uno | Microcontroller Which regulates servos, motor, and IMU | PCB board with multiple electronic components | Multiple electronic components soldered to PCB board | 0.00 |
| 2 | 1 | Bread Board | Connects arduino to servos, ESC, IMU | Plastic with solderless metal connections | Injection molded plastic parts around metal components | 0.00 |
| 3 | 2 | BDC Motor | Powers propellers, 1000kV brushless DC motor | Plastic, and metal | Metal casing was machined and assembled | 15.99 |
| 4 | 2 | ESC | Control power to motors and speed of propellers given signals from arduino. Utilized to control roll of device. | Small microcontroller wrapped in plastic | Components soldered to PCB board then wrapped in insulator | Inc. w/motor |
| 5 | 1 | IMU | Gyroscope and accelerometer detect yaw, pitch, roll of device. Transfers data to arduino to stabilize | PCB board, with accelerometer and gyroscope chips | Components soldered to PCB board | 6.99 |
| 6 | 1 | Li-Po Battery | 11.1V 1500 mA/hr 3 cell Li-Po battery | Lithium polymer in sheets of aluminum(anode) and copper (cathode) in PVC battery casing | Sheets of anode and cathode folded with a semipermeable third layer then sealed and filled with electrolyte before charging | 26.00 |
| 7 | 2 | Propeller | 8X4.5 clockwise and counterclockwise props transfer power from motors to thrust. | ABS Plastic | Injection molded | 12.99 |
| 8 | 2 | Servo | Act as mounts for each motor and control the pitch of each motor. Controls yaw, and allows for forward translation | ABS plastic | Injection molded and assembled | 10.89 |
| 9 | 2 | Uniframe Support Skis | Connect horizontal rods to baseboard, and hold ESC | PLA plastic | 3D print | .05 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 1 | Baseboard | Holds arduino and bread-board between two vertical arms | PLA plastic | 3D print | .05 |
| 11 | 2 | Extension Tube | 12in rigid carbon fiber rods that Connect vertical arms to servo mounts | Graphite | Filament wound around shaft | 2.00 |
| 12 | 2 | Servo mounts | Connect horizontal rods to servos | PLA plastic | 3D print | .05 |
| 13 | 2 | Motor mounts | Square plastic plate with a tab to mount directly to servo | PLA plastic | 3D print | .05 |
| Total Cost | | | | | | $75.06 |

| | |
|---|---|
| Team member: Erik Pranckh | Prepared by: Erik Pranckh |
| Team member: Drayton Browning | Checked by: Drayton Browning |
| Team member: Tim Roberts | Approved by: Tim Roberts |
| Team member: Jeremy Tabke | Page 2/2 |

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## *7) Testing*

| Table 7.1 | **Test Report** |
|---|---|

| **Design Organization:Mech 202** | **Date: 12/3/17** |
| --- | --- |
| Device or system tested:EPAND | |
| Objective of experiment (Engineering Specifications to be verified):<br><br>Test thrust of single motor-propeller combo. Find amount of weight that one motor can lift at full power. | |
| Methods and Materials (or Equipment):<br>Scale, Brushless motor, propeller, ESC, Arduino, power supply, mounting fixture, tape. | |
| Experimental Procedure:<br>Mount single motor on mounting fixture attached to a scale. Record weight of whole system before supplying motor with power. Turn motor on to full power and record the decrease in weight on the scale. The difference between the weight at rest and the weight at full power is the mass that one motor can lift from the ground. | |
| Results: 6x3 propeller with 1000kV motor produces 150-200 g of thrust | |
| Discussion:<br>Analysis: 6x3 prop with 1000kV motor will not produce enough lift to allow the device to fly. | Interpretation: Large diameter steeper pitch propeller will be necessary to achieve flight. 8x4 propeller was selected instead. |
| Team member: Erik Pranckh | Prepared by:Erik Pranckh |
| Team member: Drayton Browning | Checked by:Drayton Browning |
| Team member: Tim Roberts | Witnessed by:Tim Roberts |
| Team member: Jeremy Tabke | |
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Table 7.2

# Test Report

| **Design Organization: Mech 202** | **Date: 12/3/17** |
| --- | --- |
| Device or system tested:EPAND | |

| | |
|---|---|
| Objective of experiment (Engineering Specifications to be verified):<br>Test PID control code for roll stabilization. Determine whether the device can self-stabilize for roll in flight | |
| Methods and Materials (or Equipment) Broomstick, bi-copter, wire, laptop | |
| Experimental Procedure: Fix EPGND to broomstick so that it is only free to rotate about one axis, the roll axis. Balance the device and power on. If device remains stable at start bump the EPGND to initiate a roll movement, observe how the device auto corrects for the disturbance. See figure below | |
| Results: Stabilization initiates a correction, however the iterative PID responds too extremely to change in roll angle, and gets trapped in a loop of correcting itself. | |
| Discussion:<br>Analysis: Iterations of PID control are too long and infrequent so when corrections are made they are late and major movements rather than concise small movements that will lead to more stability | Interpretation: Decrease the amount of time between iterations to allow for more stable, consistent flight. |
| Team member: Erik Pranckh | Prepared by:Erik Pranckh |
| Team member: Drayotn Browing | Checked by:Drayton Browning |
| Team member: Tim Roberts | Witnessed by:Tim Roberts |
| Team member: Jeremy Tabke | |
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| | |

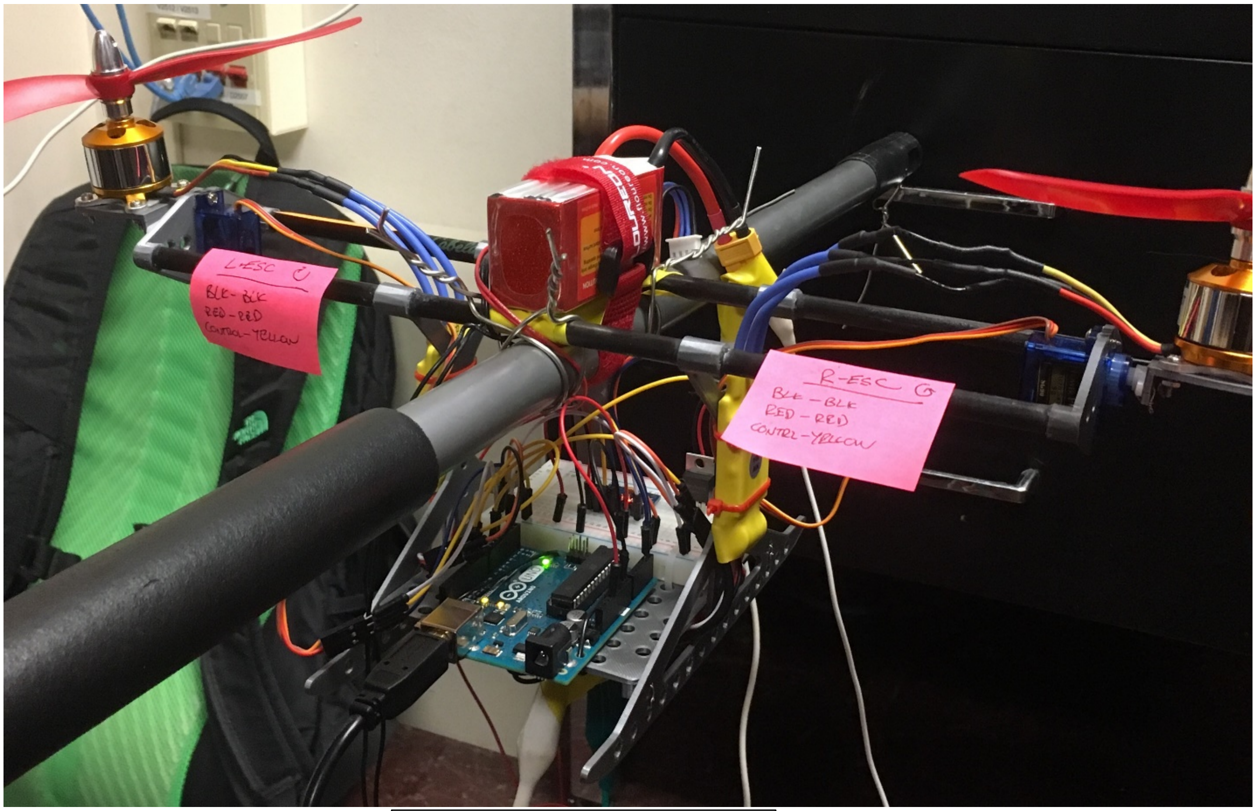


Figure 7.1 – Copter

| Table 7.3 | Test Report |
|---|---|

| **Design Organization:MECH 202** | **Date: 12/3/17** |
|---|---|
| Device or system tested:EPAND | |
| Objective of experiment (Engineering Specifications to be verified): Test flight outdoors. Determine if EPGND is capable of autonomous takeoff without a take-off platform or human interference. | |
| Methods and Materials (or Equipment) Flying device, laptop, large open space with no people. | |
| Experimental Procedure: Find large open area without pedestrian traffic. Upload most recent code to arduino. Place EPGND on level ground and initiate starting sequence. Observe how EPGND behaves in uncontrolled environment. | |
| Results: Flight was never achieved, broken motor mount, see figure below. | |
| Discussion:<br>Analysis: ESC would not arm simultaneously so one motor would start as before the other causing the device to instantly roll over. | Interpretation: ESC's need to be synchronized to provide power to each motor at the same instant allowing for level take off. More durable motor mounts need to be designed in order to with stand an impact. |
| Team member: Erik Pranckh | Prepared by:Erik Prankch |
| Team member: Drayton Browing | Checked by:Drayton Browning |
| Team member: Tim Roberts | Witnessed by:Tim Roberts |
| Team member: Jeremy Tabke | |
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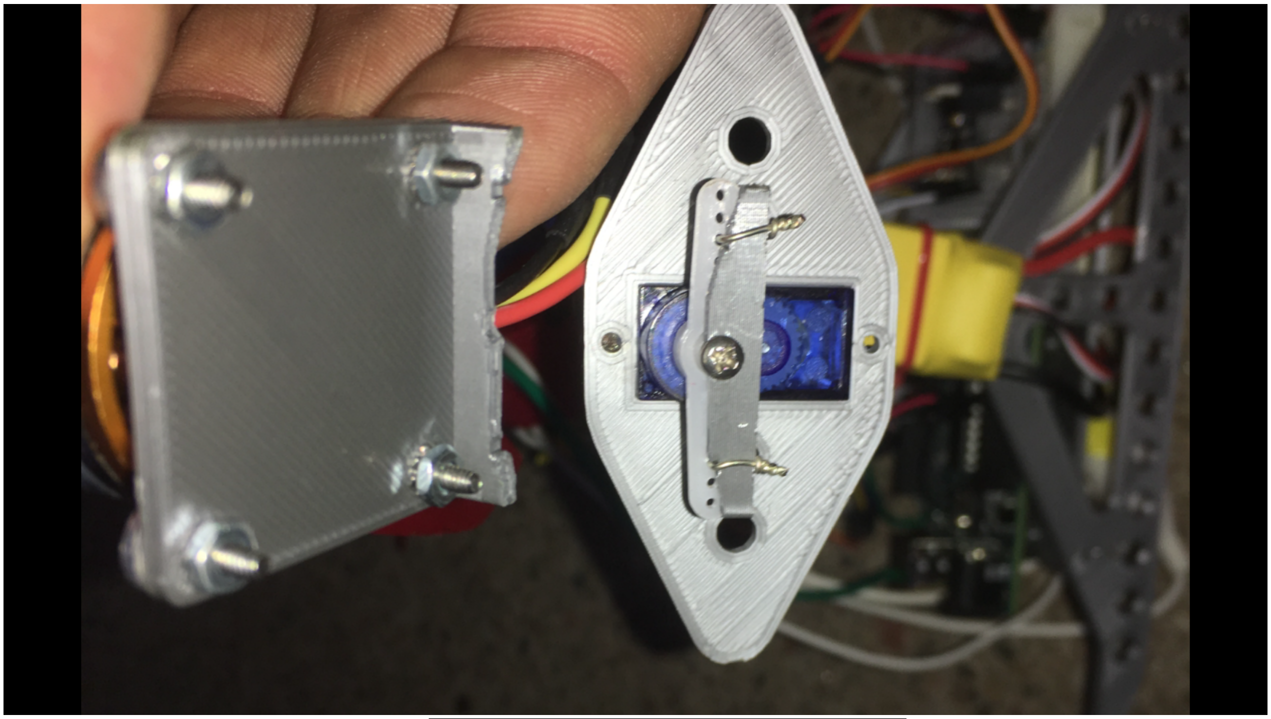

Figure 7.2 – Broken Motor Mount

## *8) Reliability and Design Margin Analysis*

Table 8.1

**FMEA (Failure Modes and Effects Analysis)**

Product: Twin Rotor Flying Device | Organization Name : Group 2

| # | Function | Potential Failure Modes | Potential Failure Effects | Potential Causes of Failure | Current Process Controls | Recommend Actions | Responsible Person | Taken Actions |
|---|---|---|---|---|---|---|---|---|
| 1 | Yaw Control | IMU malfunction, Servo malfunction, ESC malfunction | erratic flight, erratic flight, erratic flight | Faulty IMU, faulty servo, faulty ESC | IMU | Debug code, check battery voltage | Jeremy | double check code, replace IMU, replace battery, check servo |
| 2 | Pitch Control | IMU malfunction, Servo malfunction | Device will not stabilize | Faulty IMU | IMU | check connections, check code, test batt. | Jeremy | double check code, replace IMU, replace battery, check servo |
| 3 | Roll Control | IMU malfunction | Device will | Faulty IMU | IMU | check connections, | Jeremy | double check code, |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | , ESC malfunction | not stabilize | | | check code, test batt. | | replace IMU, replace battery, check ESC |
| 4 | DC Motor speed control | Flight not achieved | No lift | Insufficient power from battery | Motor Speed controler | check connections, check code, test batt. | Jeremy | secured connections , bought excessively large ESC to handle current |
| 5 | Servo/Moto r Mount | support axle, too much friction | Servos won't be able to move propeller | Too much friction | directly fixed to servo, and support axle | Redesign servo mount to eliminate support axle | Drayton | Redesigned with stronger servo mount and eliminated 2nd support |
| 6 | Base | Uneven center of gravity | Device unable to stabilize | Center of mass to high on Z-Axis. | base mounted directly to prop arms | move base below prop arms | Drayton | Designed frame to lower base below prop arms |
| 7 | Prop arms | Breaks under power | Device crashes in flight | arms to weak. | 3d printed arms | redesigned to integrate stronger carbon fiber tubes | Drayton | Redesigned servo mounts to use carbon fiber tubes instead of 3d printed arms |
| 8 | Auto Tightening propeller mount | Propeller detaches | Device crashes in flight | Propeller mount threads opposite direction of rotation | auto tightening propeller screw | manual tightening propeller screw | Drayton | Locktight to fix tightening screw. |

| | | | |
|---|---|---|---|
| Team member: Erik Pranckh | Team member: Dra yton Browning | Prepared by:Drayton Browning | |
| Team member: Tim Roberts | Team member: Jeremy Tabke | Checked by: Erik Pranckh | Approved by: Tim Roberts |



Designed by

Form # 22.0

## Reliability Analysis

Reliability calculations were based on the success and failures of our tests. All tests were rated on a pass/fail bases. If function did not perform 100% to spec it received a failure. As can be seen in the chart below (Table) our device was not highly reliable with only a .5% reliability, this correlates to about 1 successful flight out of 200. The competition reflected these results.

Table 8.2 – Reliability

| Task | Success Rate |
|---|---|
| *1)Device turned on* | 95% |
| *2)ESC armed* | 80% |
| *3)Servos operated in sync with IMU* | 79% |
| *4)ESC's armed in sync* | 15.6% |
| *5)Achieved significant movement* | 57.7% |
| *6)Achieved level flight* | 10% |
| *Reliability = (1)*(2)*(3)*(4)*(5)*(6)* | **.5%** |

## *9) Safety Analysis*

This device does pose potential risk during operation. Largely due to the propellers spinning at high velocity. Most other safety concerns can be eliminated with proper use and construction.

Table 9.1 – Safety Concern

| Safety Concern | Description | Preventative measure | Concern Level |
|---|---|---|---|
| Laceration | Sharp propellers spinning at high speeds | Use of caution during operation. Keep fingers out of propeller radius while in operation. Safety delay wen launching. | Very High |
| Electrical shock | Electrical shorts | Proper wiring using heat shrink and electrical tape to insure no exposed leads. | Very Low |

| | | | |
|---|---|---|---|
| Eye injuries | Loose parts flying at high speeds, if device fails mid flight | Safety glasses when in operation. | High |
| Head Trauma | Large device moving at high speeds. | Insure no one is in direct line of flight during operation. | Moderate |

## ***10) Service and Support Plan***

The Bi-copter is a flying device so there are many potential failures that could require in field repair. To prepare for potential repairs, it is important to have an adequate repair kit with proper tools and replacement parts.

The chassis of this device is 3D printed with PLA plastic which is susceptible to fracturing upon impact. Although 3D printing is an easy way to quickly reproduce replacement parts it is important to keep an inventory of parts on hand to insure minimal repair time during operation. Parts such as the motor mount are highly susceptible to failure during operation.

Spare drive train parts are extremely important to have on hand. Without a properly functioning drive train flight cannot be achieved and replacement drive train parts are not easily manufactured. Drive train parts however are less likely to fail than chassis parts due to their robust construction. It is especially important to keep spare propellers on hand, due to their function on the device they are moving at the highest velocity and therefore receive the greatest amount of impact in case of a crash.

| Replacement Part | Quantity | Description |
|---|---|---|
| Servo | 2 | The servo controls the movement of the propellers and is essential to flight. |
| Propeller | 4 | Provides lift to device |

| Table 10.1 – Extra Parts | 4 | Provides mounting location for motor. |
|---|---|---|
| Servo mount | | Provides mounting location for servo as well as frame support. |
| battery | 2 | Provides power to device. |

| Tools | Extra Supplies |
|---|---|
| Precision Screw Driver Set | Zip ties |
| Needle Nose Pliers | Bailing Wire |
| Wire Strippers | Electrical Tape |
| Soldering Iron | Solder |
| Heat Gun | Heat Shrink |
| Digital Multi-Meter | Battery Charger |

## ***11) Teamwork Analysis***

Erik Pranckh Reflection:

Through the duration of project two and the construction of the EPAND bi-copter I was responsible for selecting components, assembly of device, testing, collecting and formatting all critical documents for the report. Personally I feel like I worked diligently and put forth significant effort to the project. Overall I realize that our communication, and organization dynamics as a team were not ideal, throughout the semester team members were increasingly difficult to communicate with. My main contribution to the project aside from tasks assigned was doing what I could to stay on top of group communication and my attempts to have group members become more accountable teammates.

Since my knowledge of Arduino coding, and PID controlling were limited I focused on other aspects of the project such as determining which components were most compatible, assembly, and testing. Determining the proper components was critical to the function of the device since we had multiple electronic components communicating with one another they all had to be compatible with one another. Selecting a battery for example was a critical decision and required significant thought and testing with a power supply before the proper combination and discharge rate could be achieved. I was heavily involved with final assembly of the device, and testing which yielded significant vital information for the device. Along with my efforts on the device I took the lead on writing this report and formatting it appropriately.

Conclusively, my contributions to this team were very significant and we would have not achieved what we did if it hadn't been for the combined effort of all our members. One can always say in hindsight that everyone could have done more, I will remember this in my future projects in order to make sure to not leave anything on the table and put forth everything I am capable of.

Tim Roberts Reflection**:**

For project two my contributions mostly dealt with the various written portions of the report. I felt like I could have contributed more to the non-written parts of the projects, but I wasn't always actively trying to take control of these tasks since some of my group members are skilled at these tasks. As a result, I felt like my help wasn't entirely needed to complete the tasks. One thing I should have done was to start working on the many parts of the projects earlier than I did. This is something I will remember for future design projects since I feel like our final project wasn't as good as it could have been.

Overall, we worked well as a team on completing tasks on time. We worked well together and there were no major conflicts to report about. Everyone did what they were asked to do and contributed where they were needed. I believe we could have managed our time better since our final design wasn't able to reliably fly as we intended. There were a couple of time crunches that could have been avoided by meeting up for a day or two more than we had. We also could have improved our personnel management since at times one person would be working on a sizable task by themselves when other people could have probably contributed a bit. Improving this group management would have led to a more complete design that would have had a better chance at winning the competition. Even though we didn't achieve our primary goal of winning the competition, I think we all learned valuable lessons about working in a design team that we will apply in our future design challenges.

Jeremy Tabke Reflection:

For my contributions to project 2 I did all the coding for the flight controller, the research behind getting the code working and actual testing and tuning of the parameters, the 3D printing of the parts for our chassis, and all of the assembling and wiring of the actual device. I feel my contributions were more than adequate for this project. I was slightly disappointed to find out that the servos that had been purchased for the project were of too low quality to fully implement the controller I had written and only one axis of stabilization was used. In hindsight I would have purchased higher quality parts but I was trying to keep total cost of device as low as possible.

It would have been preferable if someone else in the group had experience with wiring or coding of any sort to bounce ideas off and to be able to work simultaneously. Efforts to communicate more effectively throughout the project would have helped with our likelihood of being successful as some aspects of the were delayed due to lack of communication. Although we did not get the device to successfully fly across the gym because adequate testing before the competition was not done I learned a huge amount from the failure and will likely buy better servos and get the device flying correctly in the near future.

Drayton Browning Reflection:

My contribution to Project 2 consisted mostly of chassis design. I consider myself to be fairly skilled at 3D drawing which allowed me to fill this role adequately. I made myself available as often as possible for redesign as needed through the testing and development phase and made sure to keep up with deadlines. I also made sure to fill in as needed to prepare documentation and attend prototype meetings. I believe I could have done a better job in the concept generation phase by using my 3D drawing experience to help with visual aid for decision making. Over all I am pleased with my contribution to project 2 and think that I made the appropriate changes from Project 1 to insure our group's success.

I feel as a team we all did an adequate job at keeping up with tasks. We all work together very well and have good team dynamic. Everyone pulled their weight and kept up with deadlines and due dates as best as our schedules would allow. Everyone contributed to their best ability and made sure to use their skills where they fit best. We definitely could have improved our performance in the final competition if we had started working on our project earlier in the semester although this would have proved challenging with the work load that project 1 provided. Where we were most lacking in this project was a designated group leader. With the extent of the work required I do not believe with maximized the potential of our personnel. Despite the difficulties we faced as a group I believe we all worked hard towards one final goal and made sure to make the most of this learning experience.

Lessons Learned:

Upon reflection project 2 was a valuable experience that we all learned from. It contrasted project 1 in that it required a planning and time management of us with little to no guidance in the form of assignments and class deadlines. This was the first lengthily group project for all of us so it was a steep learning curve.

The most important lesson we learned as a group is that it is important to designate a group leader. It can become challenging to stay on task without someone keeping tabs on where everyone is at along the process. This is often overlooked in a class setting because we are used to a teacher assigning due dates.

One interesting take away is that meeting too often can actually be a bad thing. Early in the project we met twice a week regardless of whether we had any important work to. This proved to be an inefficient use of our time. We should have put more effort into picking important meeting dates where we could maximize work done in a group setting. This also developed a motivation issue, we became burned out on useless meeting which resulted in us being reluctant to meet later one in the semester when we could have used more meetings.

In conclusion we all took away valuable life lessons and will use them in our future classes even though it is unlikely that we will be in the same group.

Meeting Minutes:

| Team Meeting Minutes | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 9/12/17 3:00pm - 4:30pm** |

Agenda:
1. Generate concepts for design
2. Choose concept to begin prototyping
3.
4.
5.
6.

Discussion:

Decisions Made: Decided on creating a drone for the project Focus primarily on project 1 for now

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Look for possible parts for drone | All | 10/31/17 |
| | | |
| | | |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 9/26/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| **Design Organization:Mech202 Group 2** | **Date: 9/26/17 3:00pm - 4:00pm** |
|---|---|

Agenda:
1. Discuss possible drone designs
2.
3.
4.
5.
6.

Discussion:

Decisions Made:Will proceed with a quadcopter design

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Look for possible parts for drone | All | 10/31/17 |
| | | |
| | | |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 10/4/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 10/4/17 3:00pm - 4:00pm** |

| |
|---|
| Agenda:<br>3. Create preliminary sketches for drone design<br>4. Locate drone parts online<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Will now go with a bicopter design instead of a quadcopter |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Look for possible parts for drone | All | 10/31/17 |
| Research information to help with drone build | All | 10/31/17 |
| | | |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 10/17/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |

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# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 10/17/17 3:00pm - 4:30pm** |

| |
|---|
| Agenda:<br>5. Begin a device description<br>6. Begin modeling prototype design<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Will now go with a bicopter design instead of a quadcopter |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Look for possible parts for drone | All | 10/31/17 |
| Research information to help with drone build | All | 10/31/17 |
| Device description | Jeremy, Tim, Erik | |
| 3D modeling | Drayton | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 10/19/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 10/19/17 3:00pm - 4:30pm** |

| Agenda: |
| --- |
| 1. Start engineering analysis part of report using research<br>2.<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:All will work will contribute to engineering analysis |

| Action Items | Person Responsible | Deadline |
| --- | --- | --- |
| Look for possible parts for drone | All | 10/31/17 |
| Engineering analysis | All | 11/17/17 |
| Device description | Jeremy, Tim, Erik | |
| 3D modeling | Drayton | |
| | | |

| | |
| --- | --- |
| Team member: Drayton Browning | Date for next meeting: 10/26/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
| --- | --- |
| **Design Organization:Mech202 Group 2** | **Date: 10/26/17 3:00pm - 4:00pm** |

| |
|---|
| Agenda:<br>1. Create bill of materials<br>2.<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Which parts to use for drone |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Look for possible parts for drone | All | 10/31/17 |
| Engineering analysis | All | 11/17/17 |
| Bill of Materials | Erik | 10/30/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 11/2/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 11/2/17 3:00pm - 4:30pm** |

| |
|---|
| Agenda:<br>7. Finish bill of materials<br>8. Begin testing functions of drone<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made: Which parts to use for drone |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| | | |
| Engineering analysis | All | 11/17/17 |
| Bill of Materials | Erik, Drayton | |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 11/9/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 11/14/17 3:00pm - 4:30pm** |

| |
|---|
| Agenda:<br>9. Continue testing<br>10. Safety analysis, service and support plan 3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Extend testing deadline since we didn't plan ahead for all of the testing |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Testing | Jeremy | 11/31/17 |
| Engineering analysis | All | 11/17/17 |
| Reliability & design margin analysis | Tim, Drayton | 11/31/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 11/21/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| **Design Organization:Mech202 Group 2** | **Date: 11/26/17 3:00pm - 5:00pm** |
|---|---|

| |
|---|
| Agenda:<br>11. Continue testing<br>12. Safety analysis, service and support plan<br>13. Teamwork<br>analysis 4.<br>5.<br>6. |
| Discussion: |
| Decisions Made: Gather extra material we may need for competition day (extra parts) |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Testing | Jeremy | 11/31/17 |
| Engineering analysis | All | |
| Reliability & design margin analysis | Tim, Drayton | 11/31/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 11/28/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 11/28/17 3:00pm - 5:00pm** |

| |
|---|
| Agenda:<br>14. Finish testing<br>15. Safety analysis, service and support plan<br>16. Teamwork analysis<br>17. Begin gathering documents for report<br>draft 5.<br>6. |
| Discussion: |
| Decisions Made:Make deadline for engineering analysis to 12/4/17 |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Testing | Jeremy, Erik, Tim | 11/31/17 |
| Engineering analysis | All | 12/4/17 |
| Reliability & design margin analysis | Tim, Drayton | 11/31/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 11/30/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 11/30/17 3:00pm - 5:30pm** |

| |
|---|
| Agenda:<br>1. Get ready for competition, finalize design<br>2.<br>3.<br>4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Jeremy will bring drone with him to competition day |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Testing | Jeremy, Erik, Tim | 11/31/17 |
| Engineering analysis | All | 12/4/17 |
| Reliability & design margin analysis | Tim, Drayton | 11/31/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 12/2/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 12/2/17 12:00pm - 1:30pm** |

| |
|---|
| Agenda:<br>18. Finish everything<br>19. Failure analysis (FTA)<br>20. Prepare<br>documents 4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Have materials ready for 12/4 to create report |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Prepare documentation | All | 12/4/17 |
| Engineering analysis | All | 12/4/17 |
| FTA | All | 12/4/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 12/4/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 12/4/17 2:30pm - 8:30pm** |

| |
|---|
| Agenda:<br>21. Finish everything<br>22. Failure analysis (FTA)<br>23. Prepare<br>documents 4.<br>5.<br>6. |
| Discussion: |
| Decisions Made:Gather materials in report to be ready for revisions tomorrow morning |

| Action Items | Person Responsible | Deadline |
|---|---|---|
| Prepare documentation | All | 12/4/17 |
| Engineering analysis | All | 12/4/17 |
| FTA | All | 12/4/17 |
| | | |
| | | |

| | |
|---|---|
| Team member: Drayton Browning | Date for next meeting: 12/5/17 |
| Team member: Erik Pranckh | |
| Team member: Tim Roberts | |
| Team member: Jeremy Tabke | |



# Team Meeting Minutes

| | |
|---|---|
| **Design Organization:Mech202 Group 2** | **Date: 12/5/17 9:30am - 12:30pm** |

| Agenda: | | |
|---|---|---|
| 1. Finalize report<br>2.<br>3.<br>4.<br>5.<br>6. | | |
| Discussion: | | |
| Decisions Made: | | |
| Action Items | Person Responsible | Deadline |
| | | |
| | | |
| | | |
| | | |
| | | |
| Team member: Drayton Browning | Date for next meeting: | |
| Team member: Erik Pranckh | | |
| Team member: Tim Roberts | | |
| Team member: Jeremy Tabke | | |
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<u>Team Contract:</u>

Table 11.1 – Team contract

# Team Contract

**Design Organization:** Machina ex Deo **Date:** 9/27/17

| Team Member | Roles | Signature |
|---|---|---|
| Drayton Browning | Organizer, Motivator | DB |
| Erik Pranckh | Creator, Resource Investigator | |
| Tim Roberts | Evaluator, Pusher | |
| Jeremy Tabke | Solver, Team-Worker | |

| Team Goals | Responsible Member |
|---|---|
| 1. Weekly meetings | Drayton Browning |
| 2. Adequate planning | Erik Pranckh |
| 3. Daily communication | Jeremy Tabke |
| 4. Complete tasks on time according to Gantt chart | Tim Roberts |
| 5. Get an A on the report | Tim Roberts |
| 6. Deal with possible conflicts early | Jeremy Tabke |
| 7. Organize work times at least twice per week | Drayton Browning |
| 8. Leverage strengths of each team member | Erik Pranckh |
| 9. Stay within given constraints | Tim Roberts |
| 10. | |

| Team Performance Expectations | Initial | | | |
|---|---|---|---|---|
| • Quality work to meet requirements | DB | JT | TR | |
| • Biweekly check-ins to ensure we are on track | DB | JT | TR | |
| • Project due dates met | DB | JT | TR | |
| • | | | | |
| • | | | | |

Strategies for Conflict Resolution:

- Address early
- Communicate often
- If there is a conflict in interests between two or more group members, the other group members will help mediate the issue.
- If mediation doesn't solve the issue, the team solver will decide what to do.

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***12) Failure Analysis***

Competition day did not go as well as we had hoped, by all measureable standards our device did not achieve flight. Despite our poor device performance we advanced through three rounds of the competition. On our first round our device started to take flight but due to it not being set at a high enough throttle setting it caught the edge of the ramp and crashed. This crash proved to be detrimental to our success for the rest of the competition as it resulted in a broken servo which we did not have a spare for. Even though we did not travel any measureable distance we won the round because the team we were competing against was disqualified. While we waited for the next round to start we attempted to repair our device and opted to fix the motors in place angled forward to hopefully make it over the ramp. On our second round we chose to forfeit due to some technical errors with the revised code. The third round we were able to achieve power to the propellers but without the stabilization control from the servos the device crashed before making it over the ramp.

There are a few things we could have done to improve our performance on competition day. The obvious fix would be to have had spare servos on hand so that we could have repaired our device and continued with original device function. To have avoided the initial crash entirely we could have played it a little less safe and given more power to the propellers so that it could have cleared the ramp without incident. Another option would have been to use stronger metal gear servos to avoid them failing as easily. If we had we spent more time testing the device previously to the competition we would have been more aware of this potential failure mode and could have made changes in advance to avoid device failure.

Over all we were very pleased with the performance of our device compared to similar devices we competed against, although we could have done better in the competition our Bi-Copter showed strong signs of success had it not been met with that initial incident. The opponents that chose the simpler slingshot style design out preformed any of the groups that chose the more complex forms of flight. Although we likely would not have been able to out preform the sling shot style devices we have little doubt that we could have been the most dominate Copter in the competition.

**Fault Tree Analysis:**

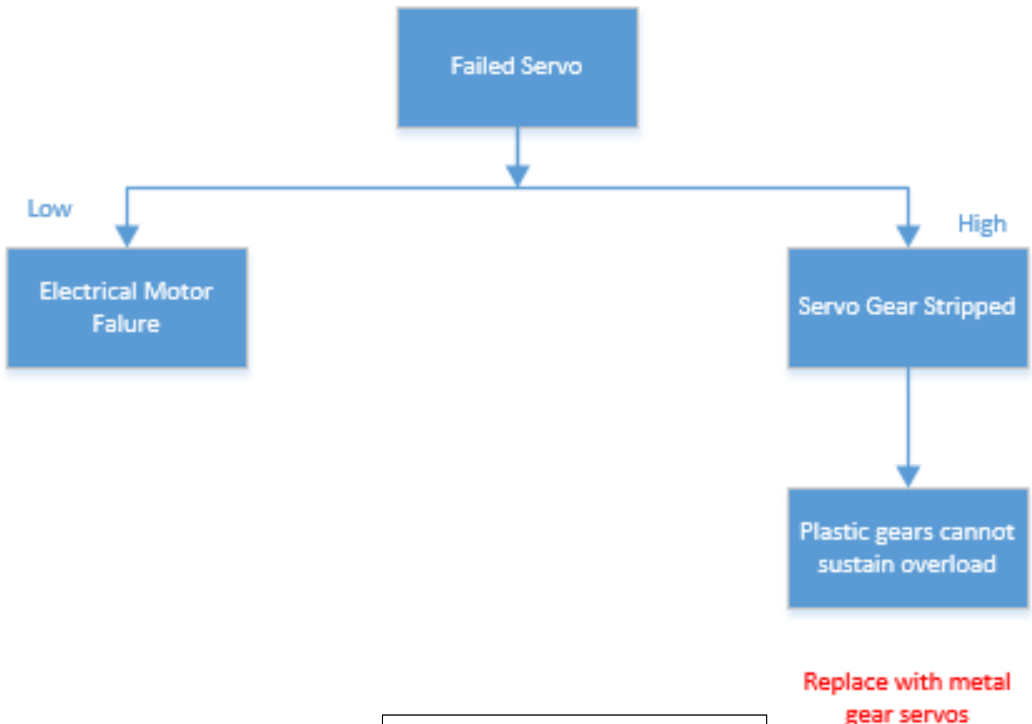


Figure 12.1 FTA

Our servo motors were common problem components since they are low quality, mass produced components designed for lower stress applications. We mounted our motors directly to the servo drive shaft which has a full plastic gear assembly. So when load is applied and the servos initiate quick reaction adjustments the gears were prone to strip completely.

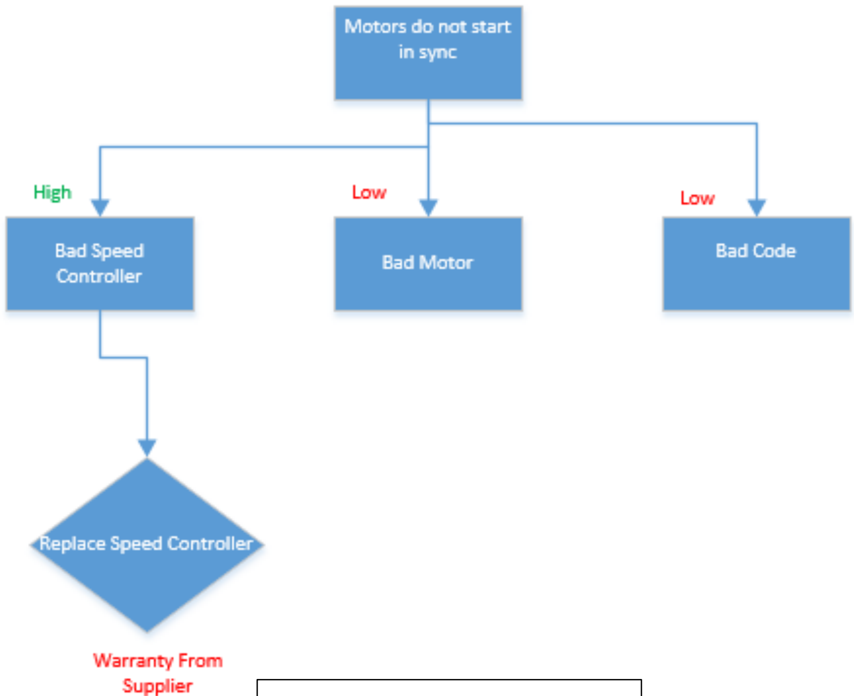


Figure 12.2 Fta

Another common problem we faced in testing was that our ESC's would not arm at the same time causing one motor to launch before the other which would flip our drone over and cause significant damage. This false start can be seen in figure () below. Through our trouble shooting process we found that we had purchase inconsistent, faulty electronic speed controllers.

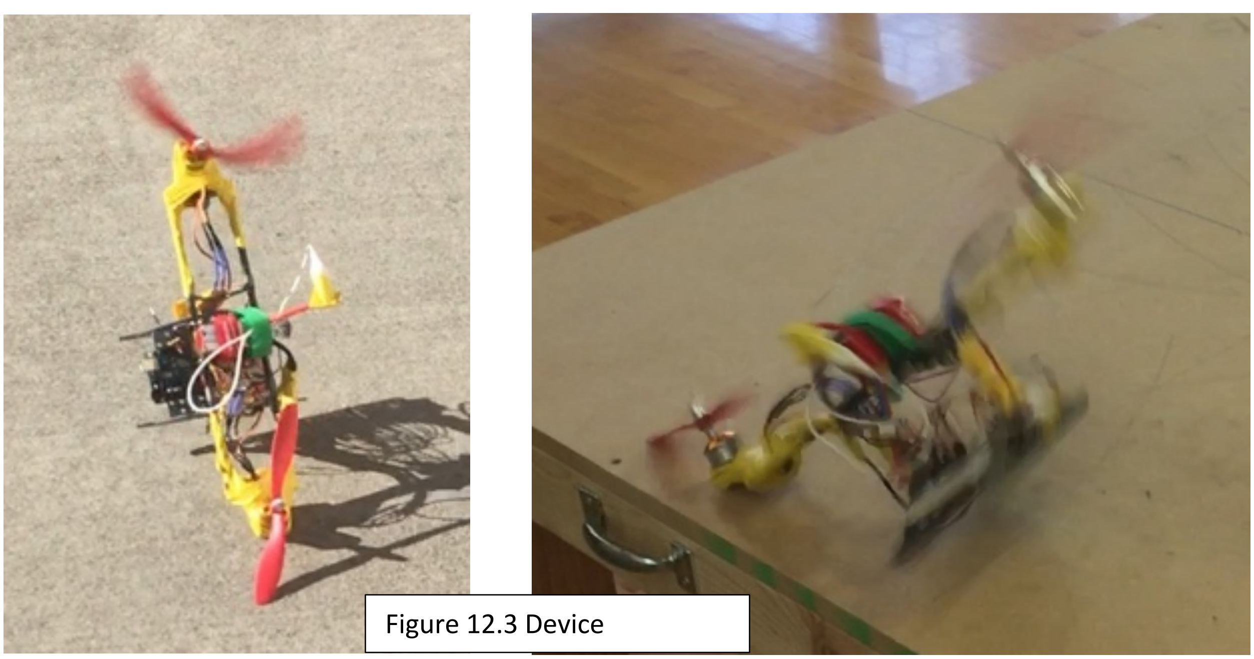

Figure 12.3 Device

## ***Works Cited***


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